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Summary

The effects of four sequential, axially aligned Borda-type inlets were studied. The authors found from a water table flow visualization study that, for separation distances less than 1 diameter, jetting could occur. For separation distances greater than 30 diameters the flow appeared to be independent of the reservoir. For separation distances between 1 and 30 diameters flow instabilities were pronounced. Subsequent experimental tests were conducted with Borda-type inlets ($L/D = 1.9$) using fluid nitrogen over a wide range of inlet stagnation pressures (to 7 MPa) and inlet stagnation temperatures (86 to 300 K). Pressure profiles and plots of flow rate at selected isotherms are presented.

At a separation distance of 30 diameters the flow appeared to be nearly independent of the upstream Bordas and reservoirs, but jetting did occur in the fourth Borda at lower inlet stagnation temperatures. The pressure profiles dropped sharply at the entrance and recovered within each tube; the exception was the last Borda, where the profile was flat.

At a separation distance of 0.8 diameter jetting was commonplace and, with the exception of the first Borda inlet, the flow appeared to be independent of the configuration. At the lower inlet stagnation temperatures the pressure dropped sharply at the first inlet and remained constant throughout, indicating jetting.

Characteristic values of flow coefficient are given as a figure at selected isotherms. At 30 diameters the flow is disrupted the most and at 0.8 diameter, the least—with a single-inlet, 53-L/D Borda tube somewhere in between. For both the 30- and 0.8-diameter separations the variation of the flow coefficient locus with reduced inlet stagnation temperature was similar to that of the single-inlet, 53-L/D Borda tube. A thermodynamic model was postulated for the 30-diameter spacing and used to predict liquid or gas flow rates, with reasonable agreement to experimental data.

Introduction

Sharp-edge as well as contoured inlet configuations are common to fluid machinery components and their complementary heat transfer devices. In many cases the details of the flow dynamics in these configurations are not well understood. Such a situation became apparent while investigating the nature of the flow of cryogens (hydrogen and nitrogen) through a shuttle high-pressure shaft seal configuration, where an unusual separation phenomenon was encountered (ref. 1 and 2). At the inlet of the third-stage seal configuration in the fully eccentric position, the flow appeared to separate and "jet" through the length of the maximum clearance channel.

Subsequent choked fluid flow tests in tubes with Borda or sharp-edge-orifice inlets (refs. 3 and 4) revealed that a jetting phenomenon could occur over a rather wide range of fluid state conditions, principally at low temperatures and high pressures, and nearly independently of the Borda or orifice inlet geometry. Data were taken for tube lengths to 105 L/D.

Flow jetting was found to be limited (1) by tube inlet stagnation temperature and to a lesser extent by pressure, (2) by tube length-diameter ratio at one extreme and by the saturation locus at the other, and (3) by tube roughness. Another unusual feature was that, even though the pressure profiles were significantly altered, the flow rates for a given isotherm were independent of the change between a jetting and a no-jetting condition. The jetting condition indicated choked flow to be controlled at the inlet rather than at the outlet. It was also found that the flow rates followed the extended corresponding-states principle (i.e., refs. 5 to 7) but that the locus of change between the jetting and no-jetting conditions did not follow the principle as well.

With these findings one could begin to understand the more complex flow phenomenon of the three-step seal (ref. 2), even though the annular passage of the seal geometry in the fully eccentric position does not have the symmetry of a tube. Furthermore, and more provocatively, the passage geometry is such as to force the flow to suffer a discontinuity in flow direction at the inlet.

The major issue now became whether jetting can occur in highly roughened tubes and/or when discontinuities exist in the geometry. In seeking answers to these problems, the authors elected to study flows through sequential inlets since the results would apply to a larger class of problems: Sequential inlets are common to axial fluid flow machinery components and labyrinth seals—to seal dynamics in particular. Furthermore sequential inlets would represent the worst type of a "roughened surface." Although the results will serve as a guide to studies on selected surface roughness, such effects were not studied in the investigation.

There may exist proprietary studies of sequential inlets, but the authors were unable to find any studies

in the literature. There are, however, studies on labyrinth seals. For example, Komotori and Mori (ref. 8) present a systematic study of one-dimensional, ideal gas flow through labyrinth seals. The calculations appear to be in good agreement with limited, but adequate, data. Although the flow through the annulus of a shaft seal configuration differs from that through the sequential Borda inlets, the similarities are felt to be significant, and the concepts presented in reference 8 are applied in this report.

During the course of this program Rohsenow (in a private communication) provided the authors with a study of water flow through a double orifice. Boscole, Martin, and Dennis (ref. 9) were primarily interested in the improvement of flowmeters. They varied parameters such as orifice diameter, axial spacing, and Reynolds number and concluded that a double orifice could be devised to give the same available head as a single orifice but with improved pressure recovery. As discussed later the results of reference 9 prompted the authors to more fully instrument the spacer sections between the four Borda inlets. With so little information available on sequential inlets a flow visualization study to quantify some parameters was undertaken.

Consequently, the purpose of this report is to provide some flow rate and pressure profile characteristics for four sequential, axially aligned Borda inlets separated by spacings of 0.8 and 30 diameters over a range of fluid pressure and temperature, as well as some results of a flow visualization study.

Flow Visualization Study

A flow visualization study was carried out on a water table to determine some characteristics of flows through sequential inlets. In previous attempts to model flows through inlets such as the Borda, sharp-edge orifice, and other modifications (refs. 3 and 4), the water table observations were found to be in good correspondence to the anticipated potential flow solutions for these inlets. Thus, to gain some insight into flows in sequential inlets, Lucite models were made of the Borda inlets using L/D dimensions and separation distances similar to those the authors expected to apply to the test apparatus. The models were then run on the water table, and selected observations were sketched as in figure 1. These sketches correspond to the photographs of figure 2. In the first sketch and photograph (figs. 1(a) and 2(a)) four Borda models were placed in such a way that they touched each other to form a continuous channel. After passing the vena contracta the flow continued uninterrupted through this configuration. The models were then placed with a separation distance of 1/3 of the channel passage width (nominally square) (fig. 1(b)). The flow still continued in an uninterrupted manner after the vena contracta. The models were then placed with a separation distance of 3/2 of the channel passage (figs. 1(c) and 2(c)). At this separation distance part of the flow entered the cavities and slight oscillations could be observed. At a separation distance of 2¼ channel passage widths a very strong oscillation was observed; the exhaust of one passage would "fan" the flow across the inlet of the subsequent Borda passage (figs. 1(d) and 2(d)). These oscillations weakened when the separation distance was increased to 4 channel passage widths (figs. 1(e) and 2(e)). A separation of 6 channel widths showed no appreciable oscillations, but the flow was still affected by the reservoir cavities (figs. 1(f) and 2(f)). At a separation of 16 channel widths the flow through each Borda passage appeared to be nearly independent of the preceding flow, although it appeared that the turbulence levels could not remain uniform throughout.

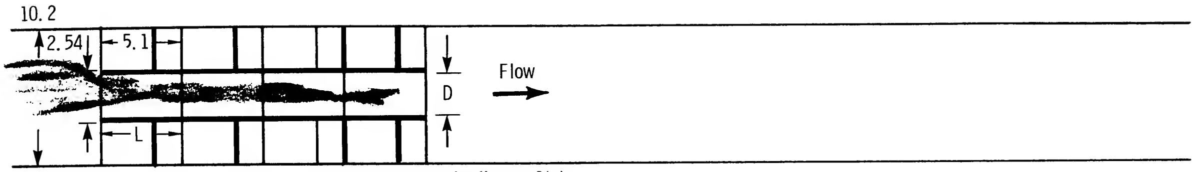
Apparatus and Instrumentation

From the water table visualization studies it became apparent that stable flow could be anticipated at small separation distances (<1 diameter) and at large seperation distances (>20 diameters). The Borda inlets were therefore designed to be similar to those used in reference 3, with spacers of 15.24 centimeters (6 in.) and 1.03 centimeters (0.407 in.). This provided two fixed spacings between the Borda inlets of 30 and 0.8 diameter, respectively.

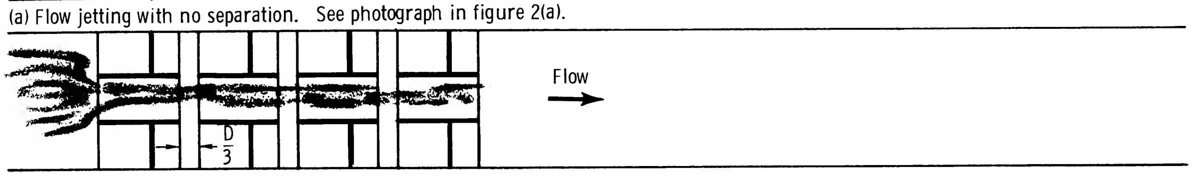
The flow facility (fig. 3) was basically that described in reference 10, but it was modified to accommodate the sequential inlet configurations. The working fluid was nitrogen.

A schematic of the geometry of the four sequential inlets with 15.24-centimeter (6-in.) spacers is illustrated in figure 4. A disassembled-view photograph of this geometry is given in figure 5, and the test section installation is shown in figure 6. During the initial runs the 15.24-centimeter (6-in.) spacers were instrumented with only a center tap because the authors anticipated that the major pressure profile changes would occur within the Borda inlets. However, upon the receipt of Rohsenow's results (ref. 9) the spacers were instrumented to better define the pressure profiles between the sequential Borda inlets. The locations of these pressure taps are given in figure 4.

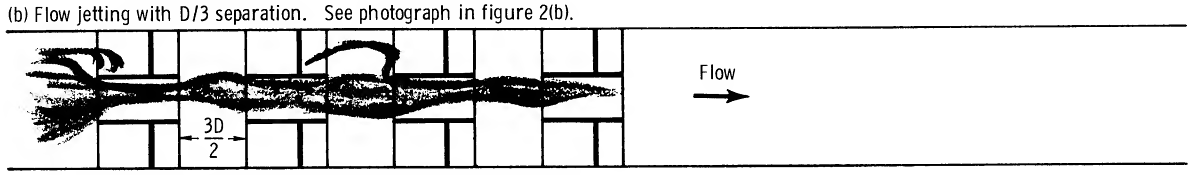
A schematic of the geometry of the four sequential inlets with 1.03-centimeter (0.407-in.) spacers is



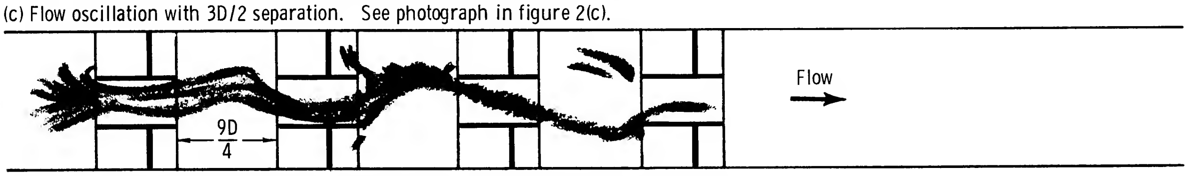
(a) Flow jetting with no separation. See photograph in figure 2(a).



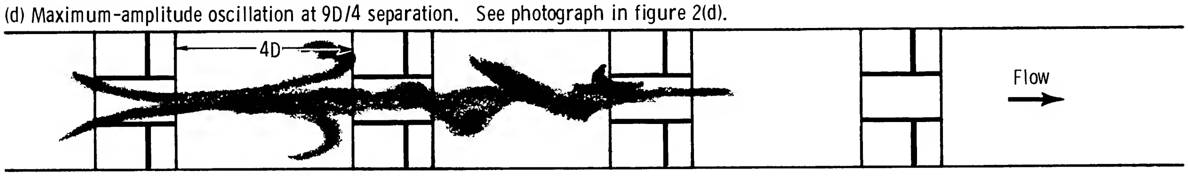
(b) Flow jetting with D/3 separation. See photograph in figure 2(b).



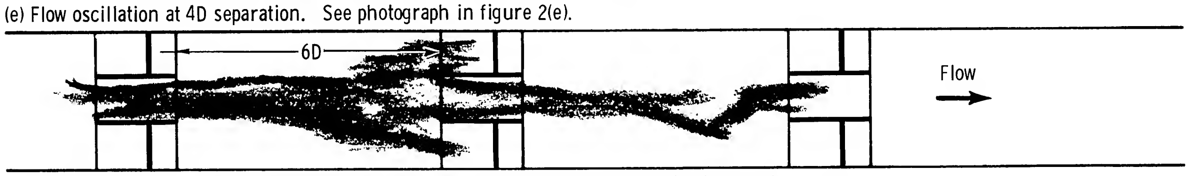
(c) Flow oscillation with 3D/2 separation. See photograph in figure 2(c).



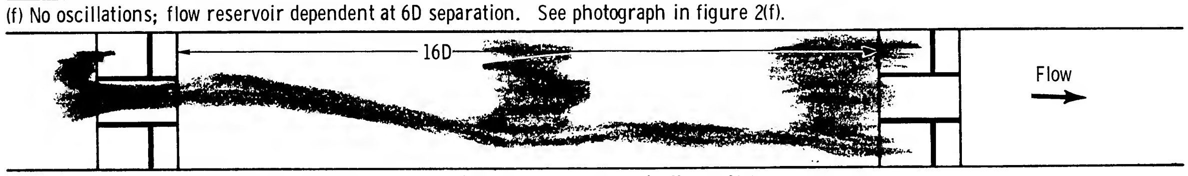
(d) Maximum-amplitude oscillation at 9D/4 separation. See photograph in figure 2(d).



(e) Flow oscillation at 4D separation. See photograph in figure 2(e).



(f) No oscillations; flow reservoir dependent at 6D separation. See photograph in figure 2(f).



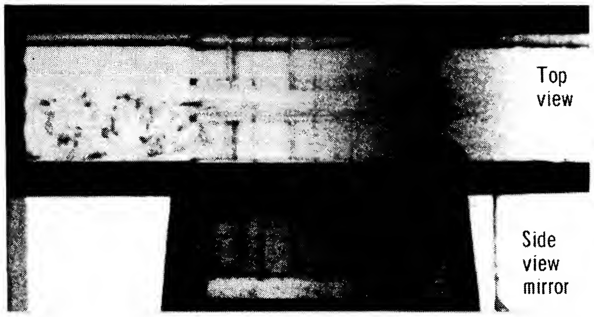
(g) Flow nearly independent of reservoir at 16D separation. See photograph in figure 2(g).

Figure 1. - Water table flow visualization of sequential Borda inlets - sketches of characteristic film frames.

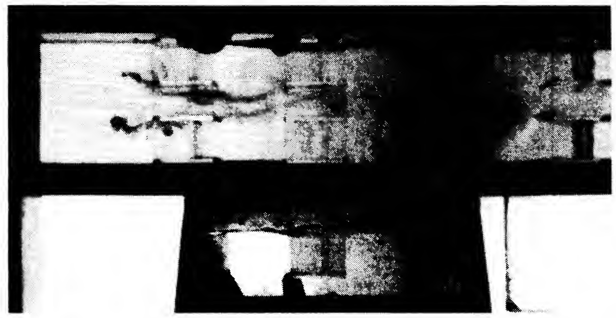
illustrated in figure 7, which also provides details of the Borda inlet geometry and pressure tap locations (fig. 7(a)). A more detailed photograph of the Borda inlet is given in figure 7(b). A disassembled-view photograph of this configuration is given in figure 8, and the test installation is shown in figure 9. The configuration was "sandwiched" between the inlet and outlet flanges to accommodate the multiple lengths, with the multiple surfaces being satisfactorily sealed by thin Mylar gaskets between the flat faces.

The pressure data were recorded on the Lewis analog-to-digital system and subsequently processed as described in reference 10. The runs were monitored, and information was displayed on a CRT with 2-second updating. However, there were insufficient available pressure channels to accommodate simultaneous recording of the pressures within and between the four sequential Borda inlets, so these data were acquired in separate runs.

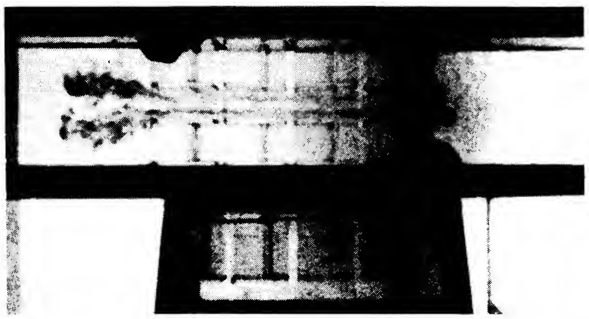
Again, the working fluid was nitrogen.



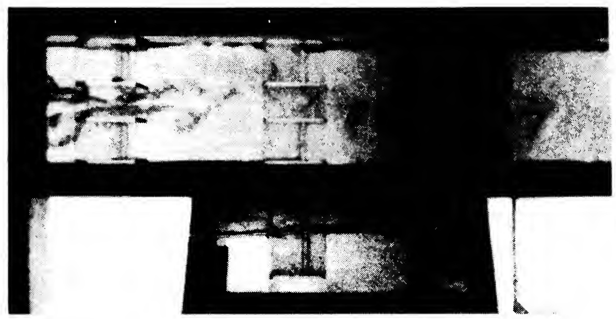
(a) Flow jetting with no separation.



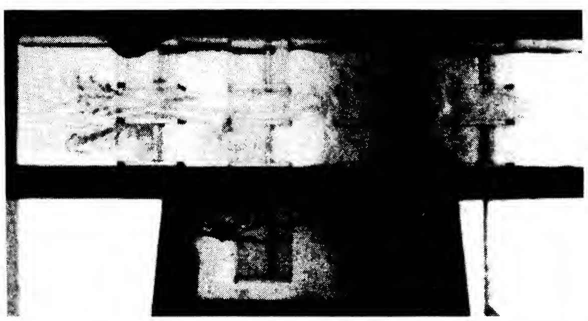
(d) Maximum-amplitude oscillation at 9D/4 separation.



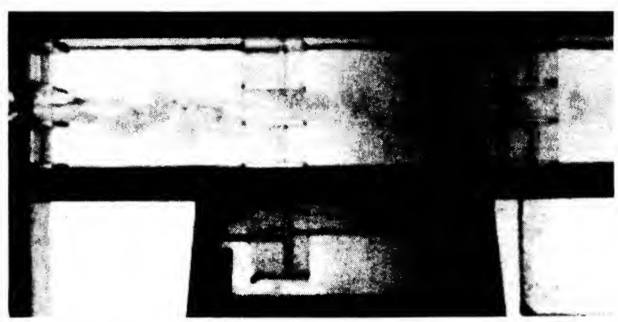
(b) Flow jetting with D/3 separation.



(e) Flow oscillation at 4D separation.



(c) Flow oscillation with 3D/2 separation.



(f) No oscillations; flow reservoir dependent at 6D separation.

(g) Flow nearly independent of reservoir at 16D separation.

Figure 2. - Water table visualization of flow in sequential Borda inlets - fluid frames.

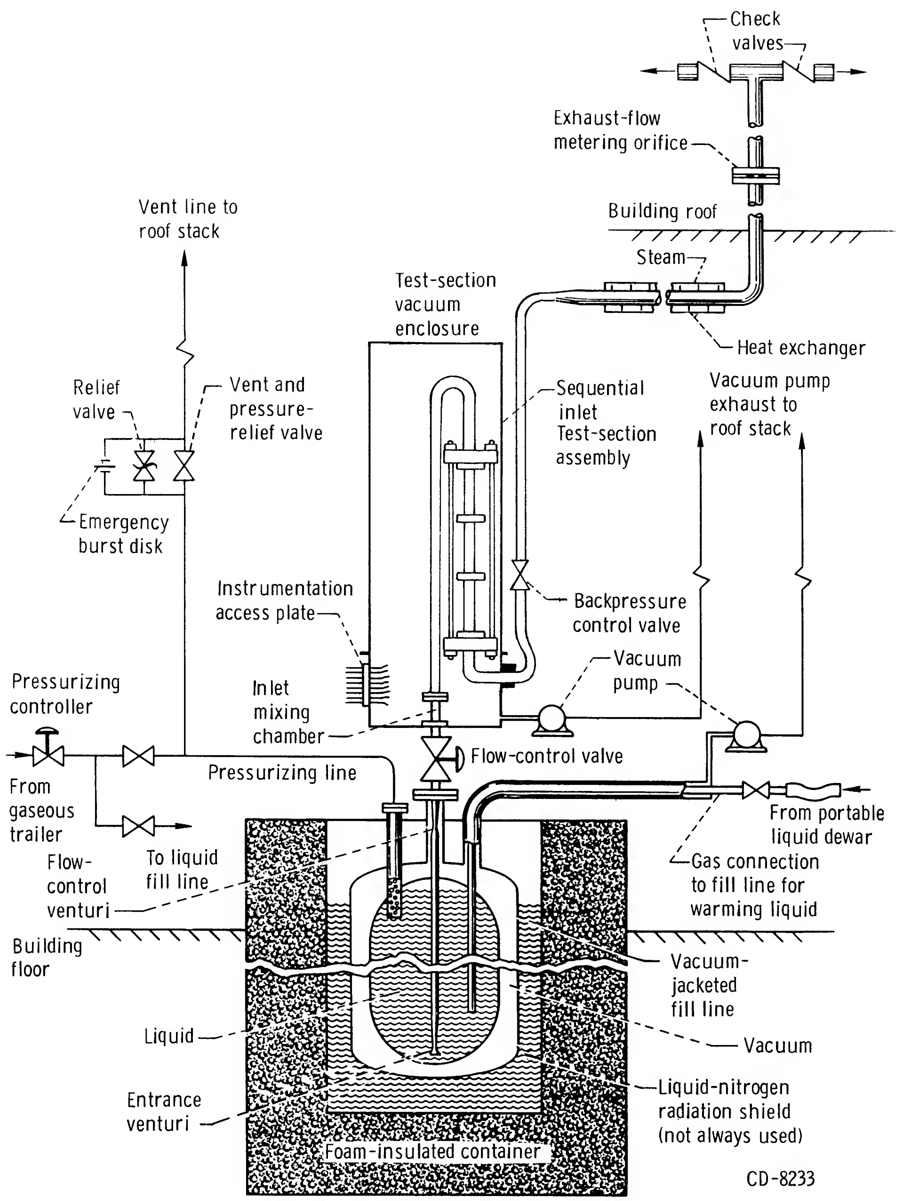


Figure 3. - Schematic diagram of high-pressure-liquid-flow apparatus with sequential Borda inlet configuration.

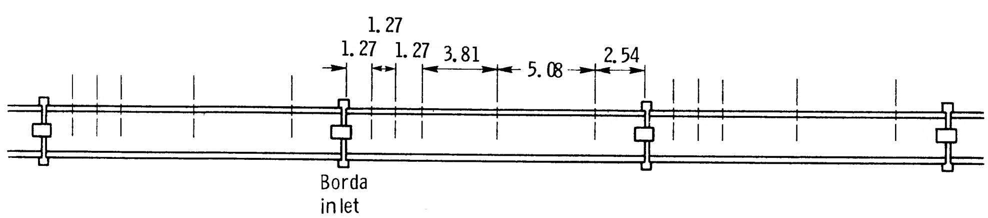


Figure 4. - Schematic of four-sequential-Borda-inlet test section with 15.24-centimeter (6-in.) spacer configuration. (See fig. 7 for details. Dimensions are in cm.)

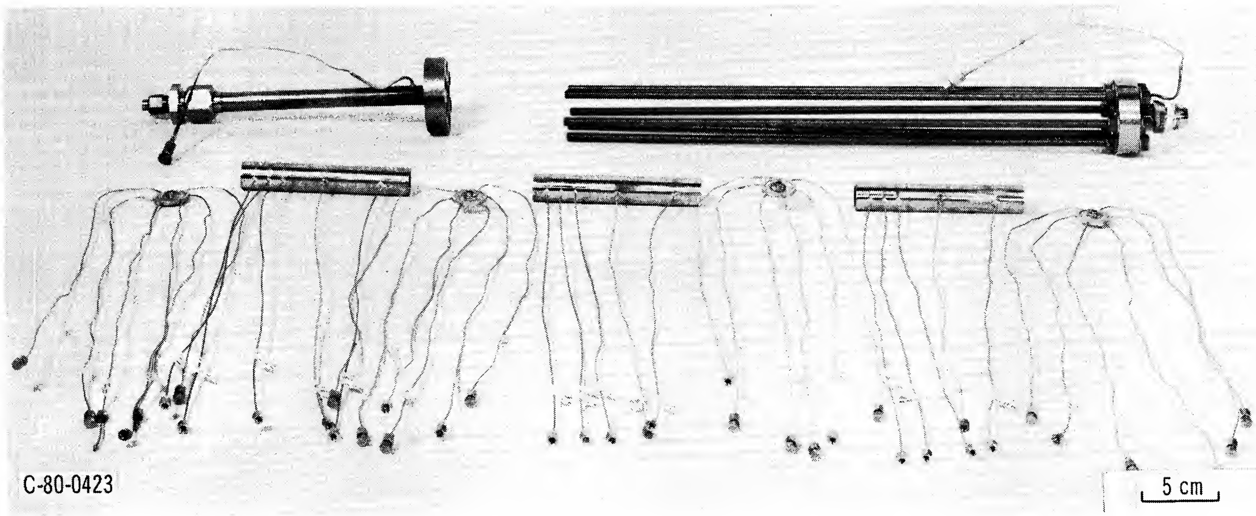


Figure 5. – Four-sequential-Borda-inlet test section with 15.24-centimeter (6-in.) spacer configuration – disassembled view.

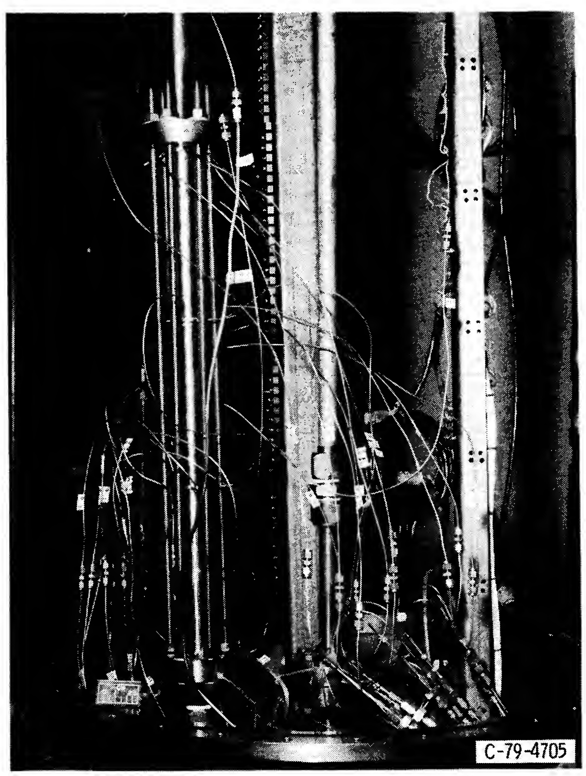
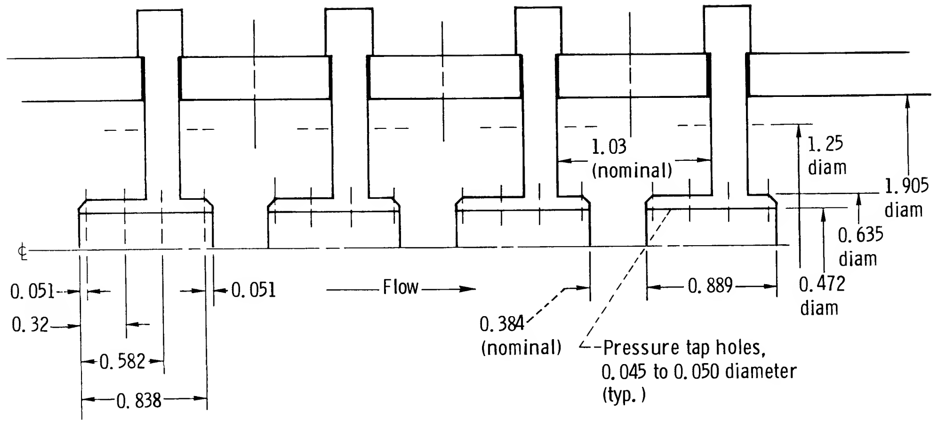
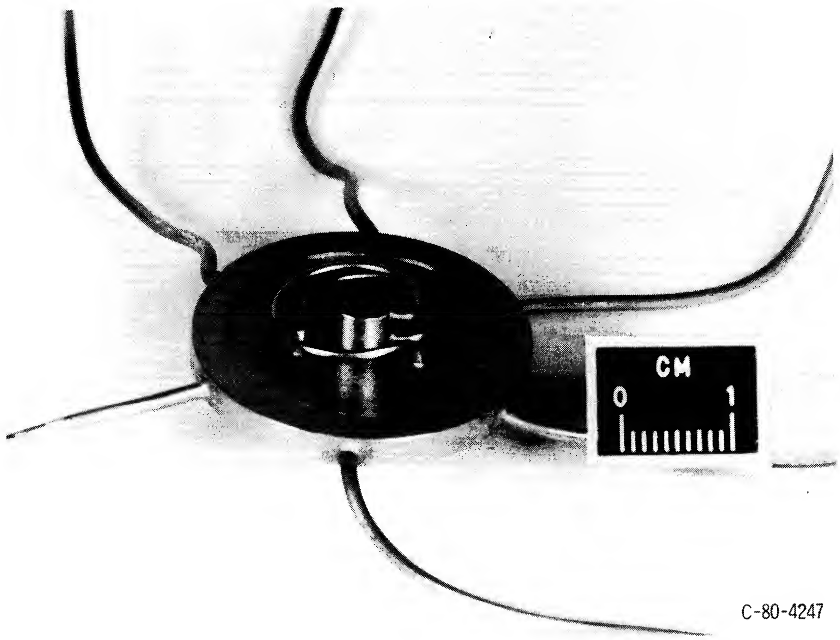


Figure 6. - Four-sequential-Borda-inlet test section with 15.24-centimeter (6-in.) spacer configuration - assembled view.



(a) Schematic of test section.



(b) An instrumented Borda inlet.

Figure 7. - Four-sequential-Borda-inlet test section with 1.03-centimeter (0.407-in.) spacer configuration. (Dimensions are in cm.)

Analysis

Common examples of sequential inlet configurations are axial-flow compressors, turbines, stage pumps, and seals. Notwithstanding the difficulties in describing the flow through these devices, we wish to consider some treatment of flow through elementary, axially aligned, sequential inlets.

The treatment even of the simplest set of sequential inlets is quite complicated. The expansion involves fluid separation, jetting, oscillations, turbulence, vortex streets, dissipation, and in many cases change of phase. Sequential expansions are perturbed in a complex way and are difficult to assess either experimentally or theoretically. One fundamental problem is that the pressure ratio across the initial stage (or subsequent stages) is unknown; consequently even the most elementary idealized treatment is not closed and requires some iteration.

In an attempt to treat the sequential inlet problem analytically, it was assumed that the entire process is adiabatic, with a series of isentropic expansions across each inlet followed by an isobaric recovery in a "mixing chamber" to the adiabatic locus as illustrated in figure 10. A procedure quite similar to

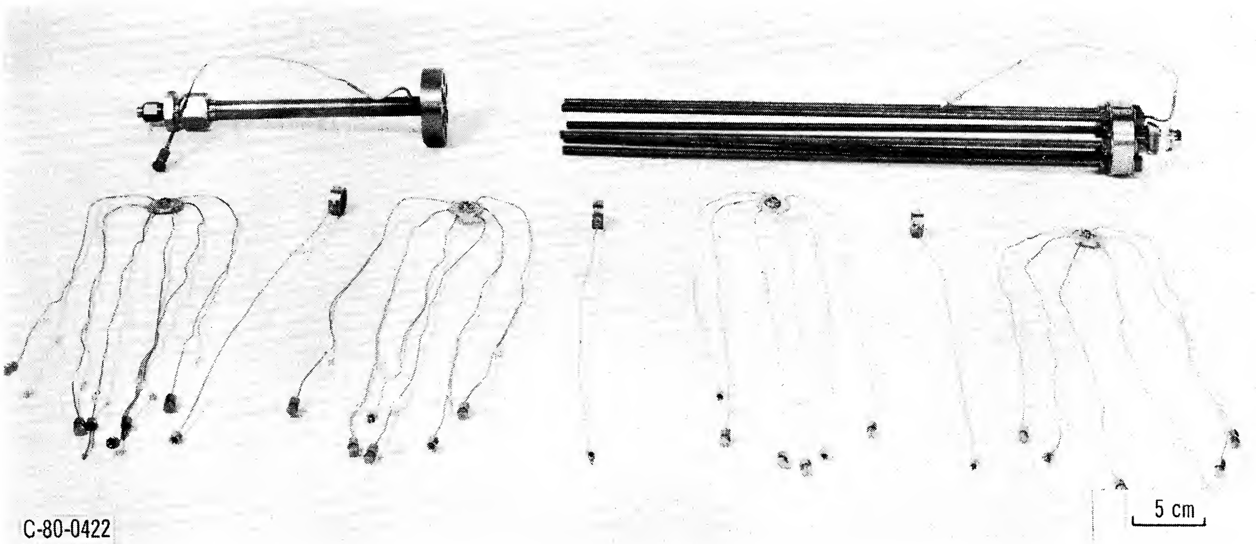


Figure 8. – Four-sequential-Borda-inlet test section with 1.03-centimeter (0.407-in.) spacer configuration – disassembled view with Borda inlet insert.

Figure 9. - Four-sequential-Borda-inlet test section with 1.03-centimeter (0.407-in.) spacer configuration - assembled view.

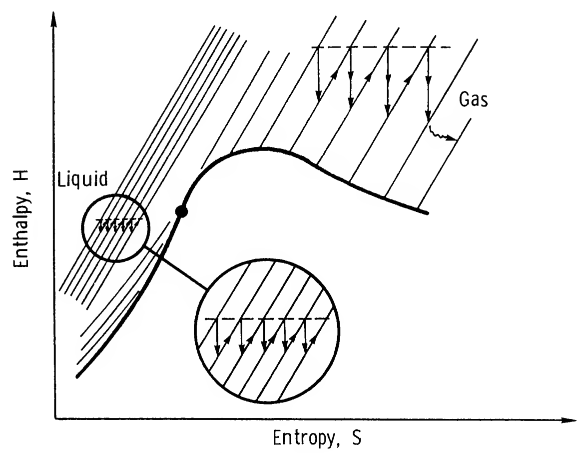


Figure 10. - Process path for four-sequential-Borda-inlet configuration on an enthalpy-entropy diagram.

this approach is given by Komotori and Mori (ref. 8) for flow through labyrinth seals.

We consider here only the simplest cases, which are those marked "gas" and "liquid" in figure 10. The flow process at the ith inlet, as described in appendix A becomes

$$G^2 = 2\rho_i^2(H_0 - H_i) \tag{1}$$

$$\Delta S_i = 0 \tag{2}$$

and the system is choked when

$$G^2 = G_{max}^2 = \rho^2 \left(\frac{dp}{d\rho} \right)_e \tag{3}$$

Although the governing equations appear straightforward, their solution is not. The computational procedure is currently being developed, and a limited number of data points for the four-sequential-Borda-inlet configuration spaced at 30 diameters are compared, tabulated, and discussed in the following section. Symbols are defined in appendix B.

Results

Experimental Comparisons

Although the pressure profiles are perhaps of greater interest, the flow rates are more conventional and are therefore presented first. Also, the results are divided into those for the 30-diameter separation distance and those for the 0.8-diameter separation distance. The data for these separations are further subdivided into instrumented and uninstrumented spacer sections. Data for the 30-diameter separation instrumented spacers are presented as table I, and those for the 30-diameter-separation uninstrumented spacers in table II. Data for the 0.8-diameter-separation instrumented spacers are presented in table III, and those for the 0.8-diameter-separation uninstrumented spacers in table IV.

As the current system instrumentation is for steady flows, separation distances between 1 diameter and 30 diameters were not run, since flow instabilities were anticipated with this range of separation distances.

Four sequential inlets at 30-diameter separation.—In references 3 and 4 the flow rates were ratioed to those predicted for two-phase choked flow through a venturi. This ratio is defined as the flow coefficient. Even though in this experiment four such Borda inlets were aligned axially and using the flow coefficient belied understanding of the flow details, we applied the same technique.

The flow coefficient for the four-Borda-inlet configuration becomes

$$C_F = \frac{G_R}{G_{R,venturi}} \tag{4}$$

where

$$G_R = \frac{G}{G^*} \tag{5}$$

represents the reduced flow rate and G^* can be determined from the extended corresponding-states principle (refs. 6 and 7) and appendix A. Although no verification of the extension of results herein to other fluids is presented, references 5, 6, 7, and 11 suggest that the principle can be applied.

Reduced flow rate data as a function of reduced inlet stagnation pressure for selected isotherms are presented in figure 11. For the 0.68-reduced-inlet stagnation temperature isotherm the flow coefficient C_F is 0.36, but for gas the value of C_F increases to 0.52. This trend is not unusual and was found for the tubes with single Borda-type and sharp-edge orifice inlets to 105 L/D (refs. 3, 4, and 12). The flow coefficient locus for a 53-L/D tube with a single Borda-type inlet can be used as a background or reference curve (ref. 3) for figure 12. The variation of the data with reduced stagnation temperature is given in figure 13, where the deviation bars represent uncertainties (e.g., with pressure) at the selected isotherms. The nonequilibrium model (ref. 11) allows a certain degree of metastability, which becomes increasingly important for inlet stagnation pressures approaching saturation; and higher flow rates are

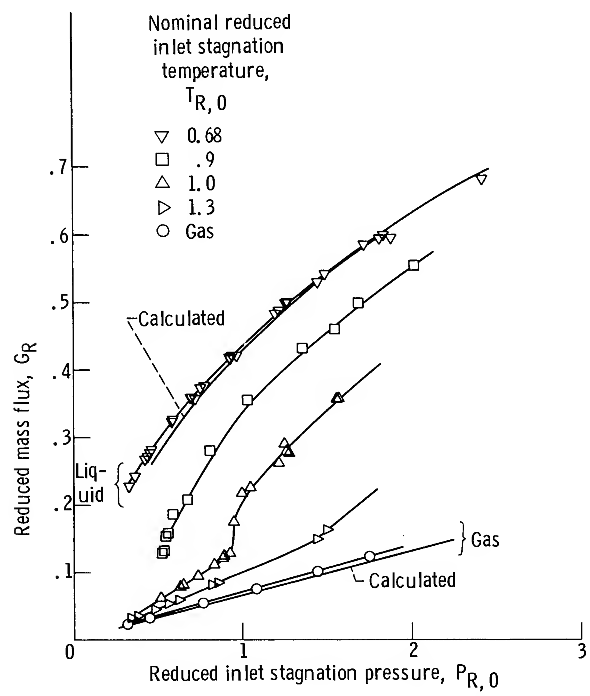


Figure 11. - Reduced mass flux as a function of reduced inlet stagnation pressure for four sequential Borda inlets separated at 30 diameters - 15.24-centimeter (6-in.) spacers.

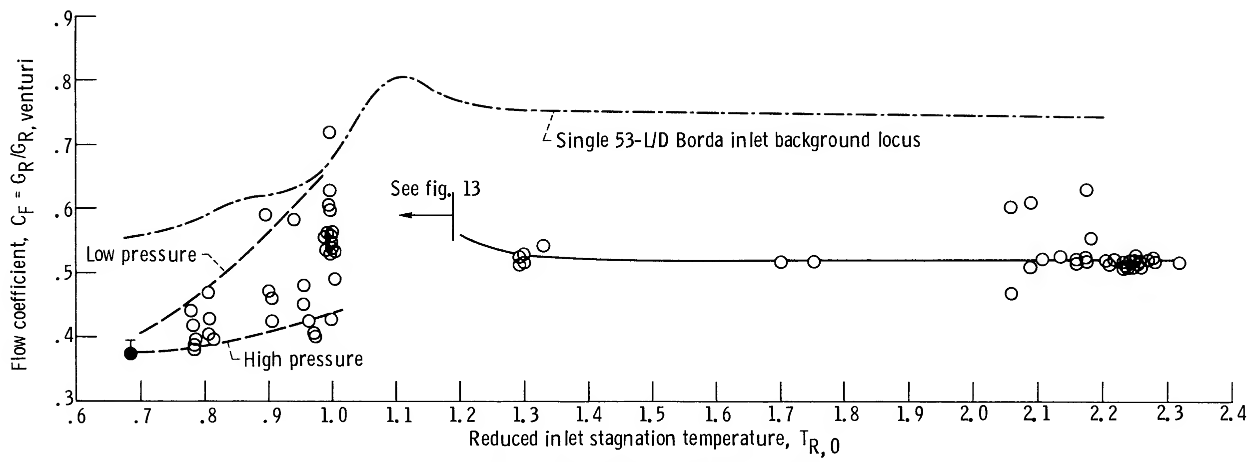


Figure 12. - Flow coefficient as a function of reduced inlet stagnation temperature for four sequential Borda inlets separated at 30 diameters - 15.24-centimeter (6-in.) spacers.

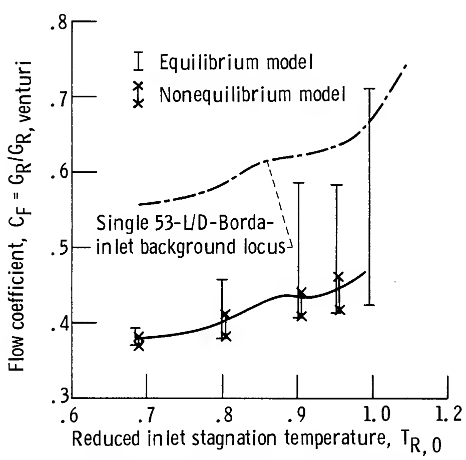


Figure 13. - Flow coefficient data deviations for the equilibrium and nonequilibrium models and recommended curves - four sequential Borda inlets separated at 30 diameters (15.24-cm (6-in.) spacers); reduced inlet stagnation temperature, $T_{R,0} < 1$.

predicted over those of the equilibrium model in this region. When the nonequilibrium model is used at the lower pressures, the deviation bars can be reduced significantly. However, the deviation bands still persist, especially in the near-critical region.

The recommended flow coefficient curves are given in figure 13. The curve was terminated near a reduced temperature T_R of 1 for two reasons: our limited understanding of the near-critical fluid behavior, and the substantially reduced scatter for flows where $T_R > 1$.

As pointed out earlier the flow coefficient technique does little to represent understanding of the complex four-sequential-inlet flow phenomenon, but it is expedient and characterizes the blackbox nature of the system.

An insight into the complex nature of the flow through the four sequential inlets is provided by the pressure profiles given in figures 14 to 16. If one were unaware of the four Borda inlets spaced at 30 diameters and had only the stagnation pressures at the inlet (or outlet) of each and connected these points, one would presume that the profiles were those of a tube with substantial surface roughness (fig. 15). It is apparent from the details that such is not the case. There exists a rather sharp drop in pressure near the entrance of each of the four sequential Borda inlets, as given in more detail in figures 14 and 16. The pressure drop is generally followed by a recovery but, in the case of the liquid-like flows, jetting is assumed to occur in the last inlet configuration from the nature of the "flat" pressure profile. Such behavior is quite similar to that of the shuttle seal configuration (refs. 1 and 2) that instigated the study.

The spacer pressure profiles exhibited in reference 9 for water flow through inlet orifices are similar to those found within the Borda inlets. Although there was no reason to anticipate large axial variations in spacer pressure profiles as exhibited in reference 9, some data were taken with 15.24-centimeter (6-in.) instrumented spacers (fig. 15). The results were much as anticipated and the effect appears small. However, a jet should create a pressure lower than measured somewhere in the spacer.

The pressure profile variations with inlet stagnation temperatures are illustrated in figure 16. As anticipated from previous work the pressure level of the "flat" profile in the last sequential inlet is very close to the saturation pressure as determined by the inlet stagnation temperature (refs. 2 to 4). As the

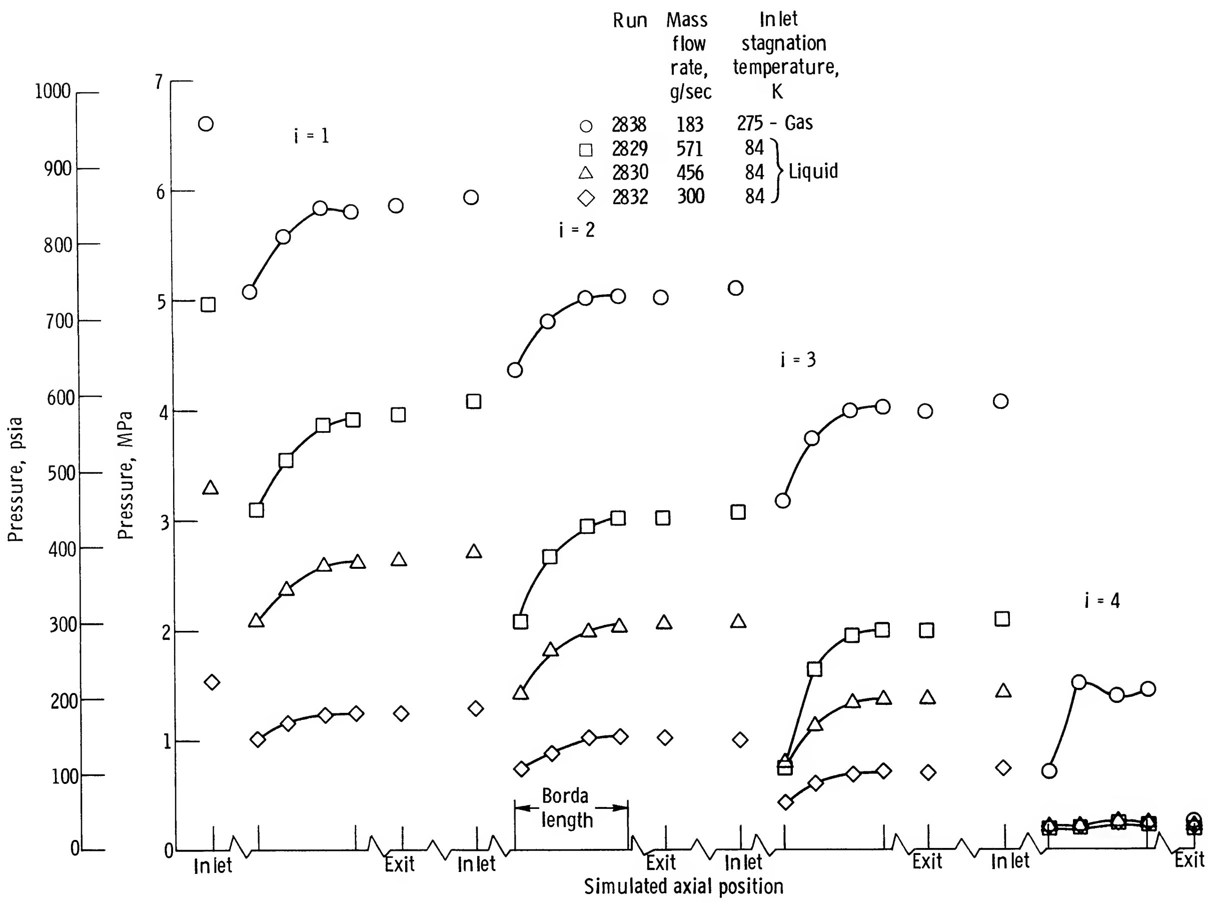


Figure 14. - Pressure profiles for four sequential Borda inlets separated at 30 diameters with 15.24-centimeter (6-in.) spacers - simulated axial position.

inlet stagnation temperature is increased, the saturation pressure is increased; and so the minimum pressure level of the flat profile is increased.

While the choked flow condition was not verified for all runs, the backpressure was varied at the lower inlet stagnation pressure in order to verify that the flow was indeed choked.

Four sequential inlets at 0.8-diameter separation.— The authors assumed from the flow visualization studies that at an 0.8-diameter separation distance, the fluid would flow undisturbed by the spacer discontinuities; that is, flow jetting would be a distinct possibility.

Again, we first look at the flow rates. The reduced flow rate for the four sequential inlets with 0.8-diameter separation as a function of reduced pressure for selected isotherms is given in figure 17. As was the case for 30-diameter separation the flow coefficient varies—here from 0.55 for liquid to nearly 0.75 for gas. And for a background similar to that in figure 12, the variation in flow coefficient with reduced temperature is given in figures 18 and 19. Although the level is changed, the trends appear to be similar to those of figures 12 and 13 and that of a tube with a single Borda inlet (refs. 3, 12, and 13).

A most dramatic change due to the flow separation occurs in the pressure profiles for both gas and liquid as well as those for the fluid states in between. As can be seen from figures 20 and 21 the pressure profiles through the first inlet exhibit a sharp drop at the entrance, remain somewhat constant for the intermediate stages, and—depending on the fluid structure—may or may not exhibit a sharp drop near the exit of the last inlet configuration. The gas pressure profiles give the appearance of a flow that is nearly choked at both the inlet and the outlet.

Although the liquid profiles are those of a free jet, analogous to those noted for tubes with single Borda or orifice inlets, it was necessary to establish that recovery did not occur between the inlets. Subsequent pressure measurements in the spacer chambers revealed little or no pressure variation between the sequential stagnation or interchamber pressure at the outlet of one Borda and that at the

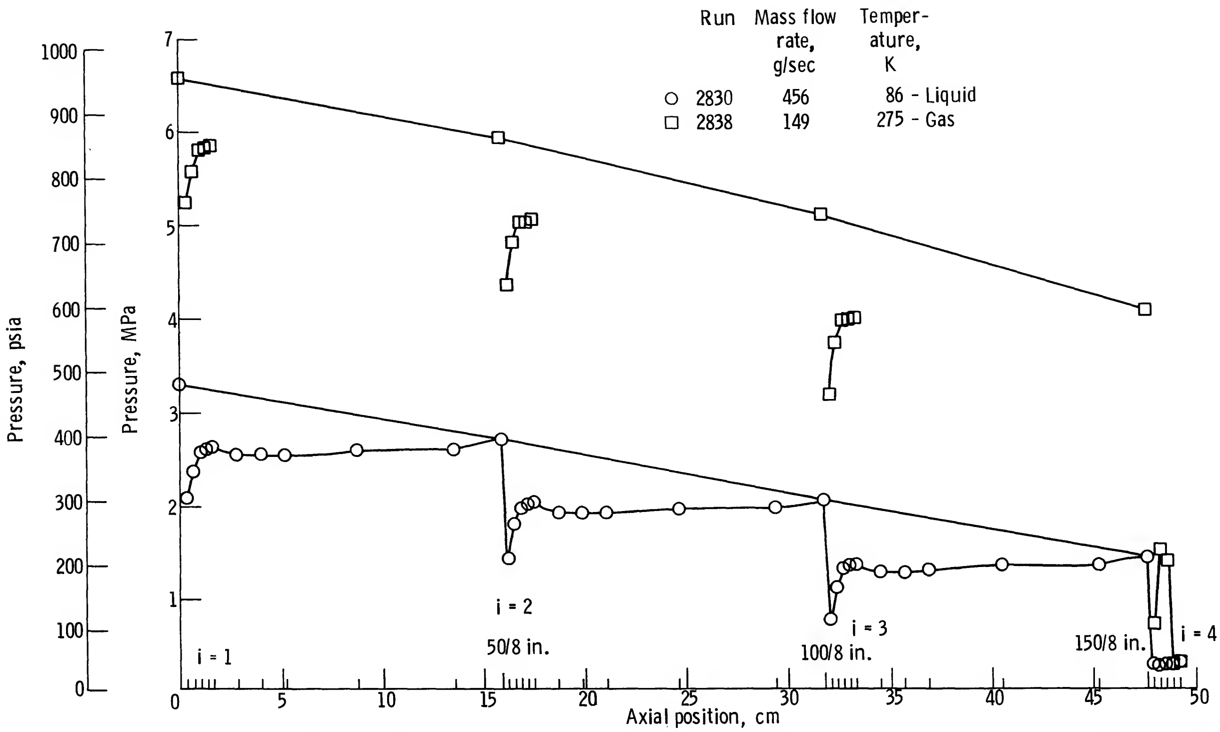


Figure 15. - Pressure profiles for four sequential Borda inlets separated at 30 diameters with 15.24-centimeter (6-in.) spacers - axial position.

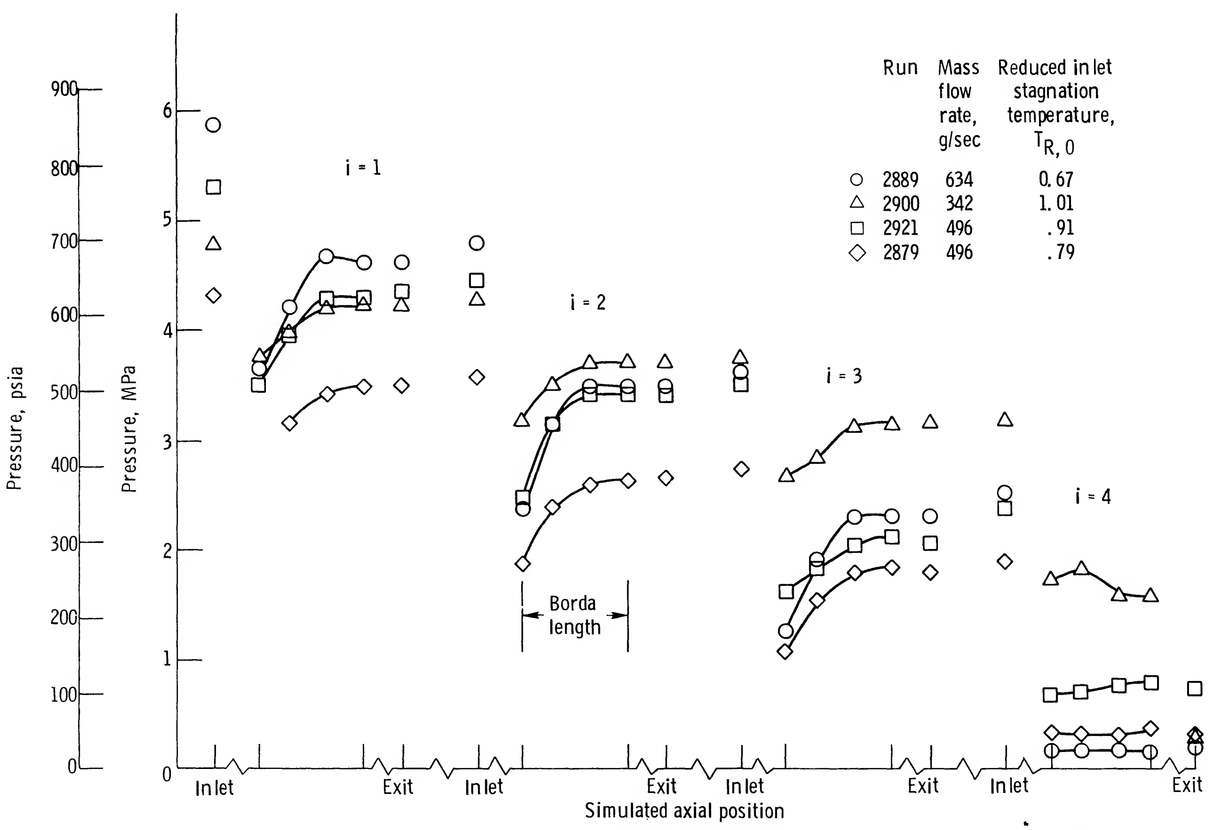


Figure 16. - Pressure profiles for four sequential Borda inlets separated at 30 diameters with 15.24-centimeter (6-in.) spacers - simulated axial position with variable reduced inlet stagnation temperature.

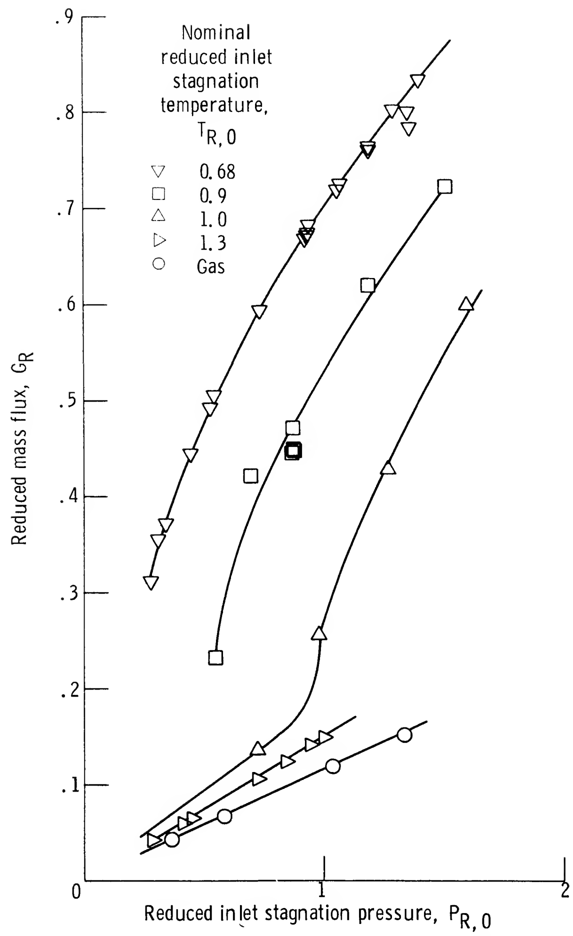


Figure 17. - Reduced mass flux as a function of reduced inlet stagnation pressure with selected isotherms - four sequential Borda inlets separated at 0.8 diameter with 1.03-centimeter (0.407-in.) spacers.

entrance of the subsequent one (see figs. 5 to 9 for geometry). This of course means that under these conditions the fluid can flow unimpeded from the first inlet through the four sequential inlets, even though they are separated by spacer lengths of 0.8 diameter.

The variation in pressure profile level with inlet stagnation temperature are illustrated in figure 21. As can be seen the jetting phenomenon is pronounced even at the higher inlet stagnation temperatures, and again the pressure level appears to be that associated with the saturated stagnation temperature.

Generally jet flows are sensitive to exhaust pressures, or so-called backpressure. Backpressure applied to a choked flow system will usually have no major effect on upstream pressures—up to a point, after which the flow goes unchoked. To see how backpressure affected the flow and/or pressure profiles, a series of tests were run in which the backpressure was varied; some results are given in figure 22. As noted in other tests (refs. 2 to 4) recompression within the tube and, for these data, within the sequential inlets is insensitive up to a point and then becomes extremely sensitive to small perturbations. Although more work needs to be done to fully establish the effects of backpressure, it is clear that jetting can still occur at backpressures substantially above those within the four sequential inlets (see also refs. 2 to 4).

These results demonstrate that jetting can occur even with disjoint sequential inlets and high backpressures and further defines the nature of the flow separation in the three-step seal (ref. 2). Such controlled separations can be useful in providing high seal stiffness, high blade loading, fluidic

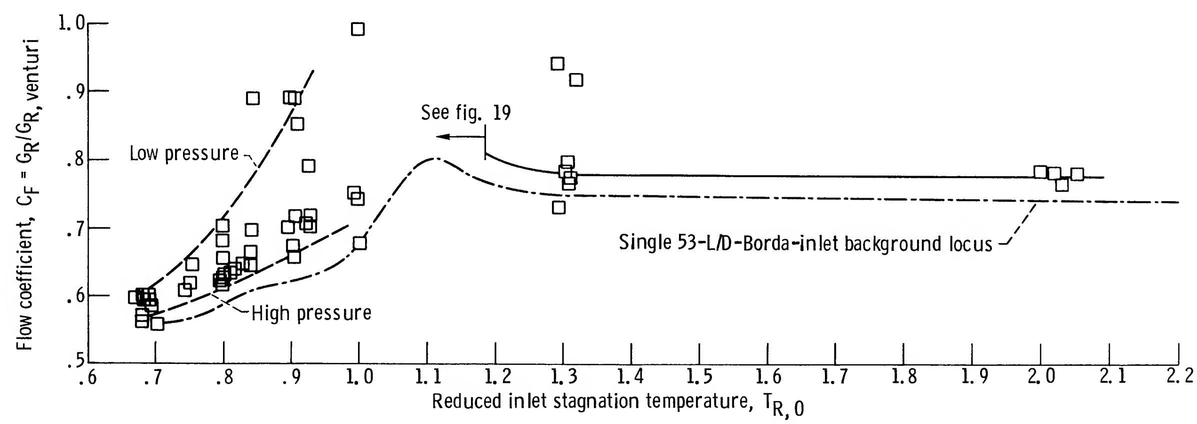


Figure 18. - Flow coefficient as a function of reduced inlet stagnation temperature for four sequential Borda inlets separated at 0.8 diameter - 1.03-centimeter (0.407-in.) spacers.

control, ejector flow, etc. However, they can be equally harmful when they are uncontrolled.

Analytical Comparisons

In general, the gas data are easier to handle than the liquid; however, for either case, one must assume (1) the pressure ratio across the first inlet, (2) that the choking condition applies to the last Borda inlet, and (3) that the iteration will converge to the solution. The results of selected computations are given as table V. For these cases a flow coefficient of 0.75 was chosen as representative of the system and held constant for each inlet. This of course is a crude assumption but an expedient one at this point in the development of a solution for the system. The calculated liquid and gas locii are presented in figures 12 and 13.

For the limiting case of a perfect gas the results of this analysis are in good agreement with the results of Komotori and Mori (ref. 8). In many cases Komotori and Mori's approach can be applied even though there are real gas effects, and better solution stability will be achieved.

Problems of convergence are ever present. For example, run 3051 (table V) appeared to converge for the pressure ratio $X_{4,calc} = 0.44$ but in fact it should have converged at $X_{4,calc} < 0.27$. At $X_{4,calc} = 0.44$ the flow rates and pressure ratios at each Borda inlet appear acceptable; however, deliberate forcing of the computation to $X_{4,calc} < 0.27$ effects a substantial departure in the pressure ratios but gives better agreement with the flow rate. A similar difficulty is experienced with run 3056, except that here the $X_{4,calc} = 0.8$ was determined to be incorrect and $X_{4,calc} = 0.675$ to be more realistic. A great deal of effort must be applied here before we can achieve a solution. In the meantime the "blackbox" approach

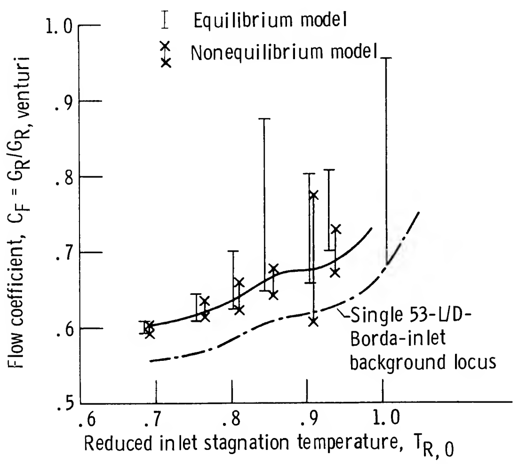


Figure 19. - Flow coefficient data deviations for the equilibrium and nonequilibrium models and recommended curves - four sequential Borda inlets separated at 0.8 diameter (1.03-cm (0.407-in.) spacers).

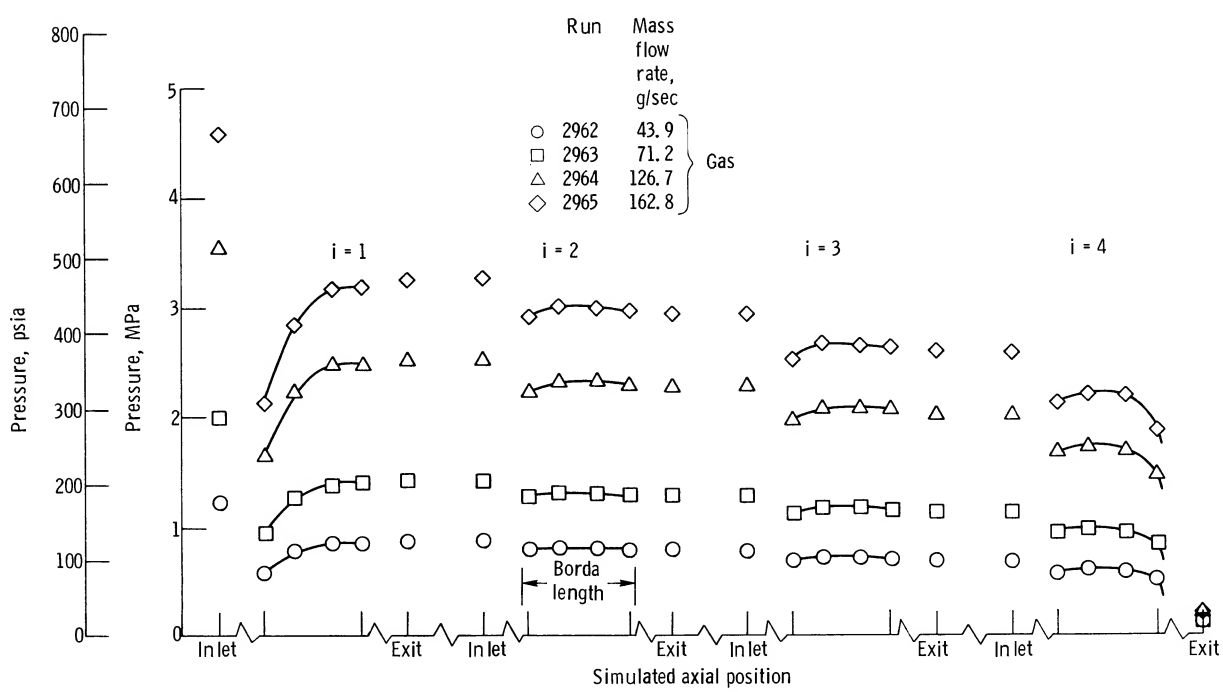
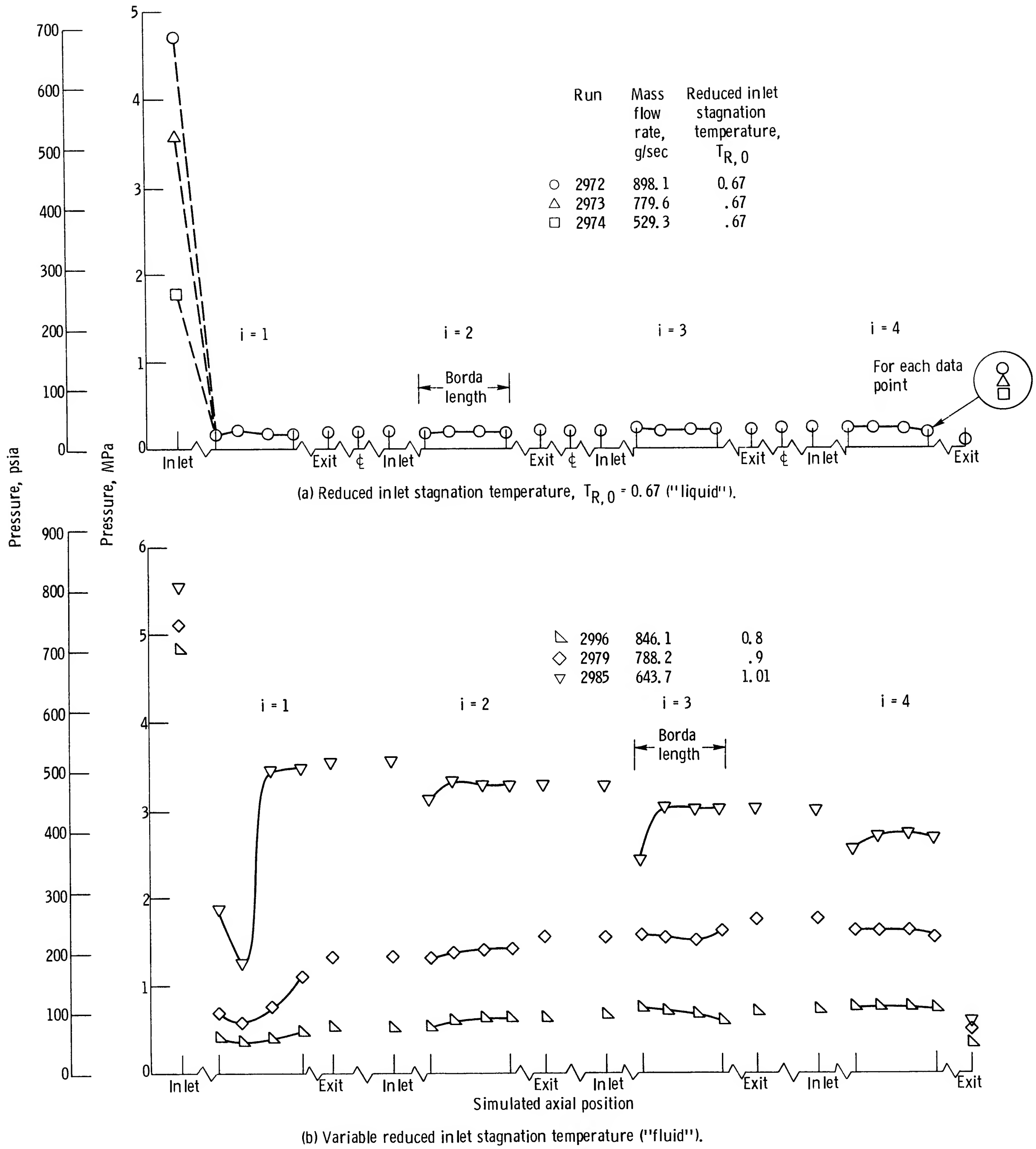


Figure 20. - Pressure profiles for four sequential Borda inlets separated at 0.8 diameter with 1.03-centimeter (0.407-in.) spacers - simulated axial position.



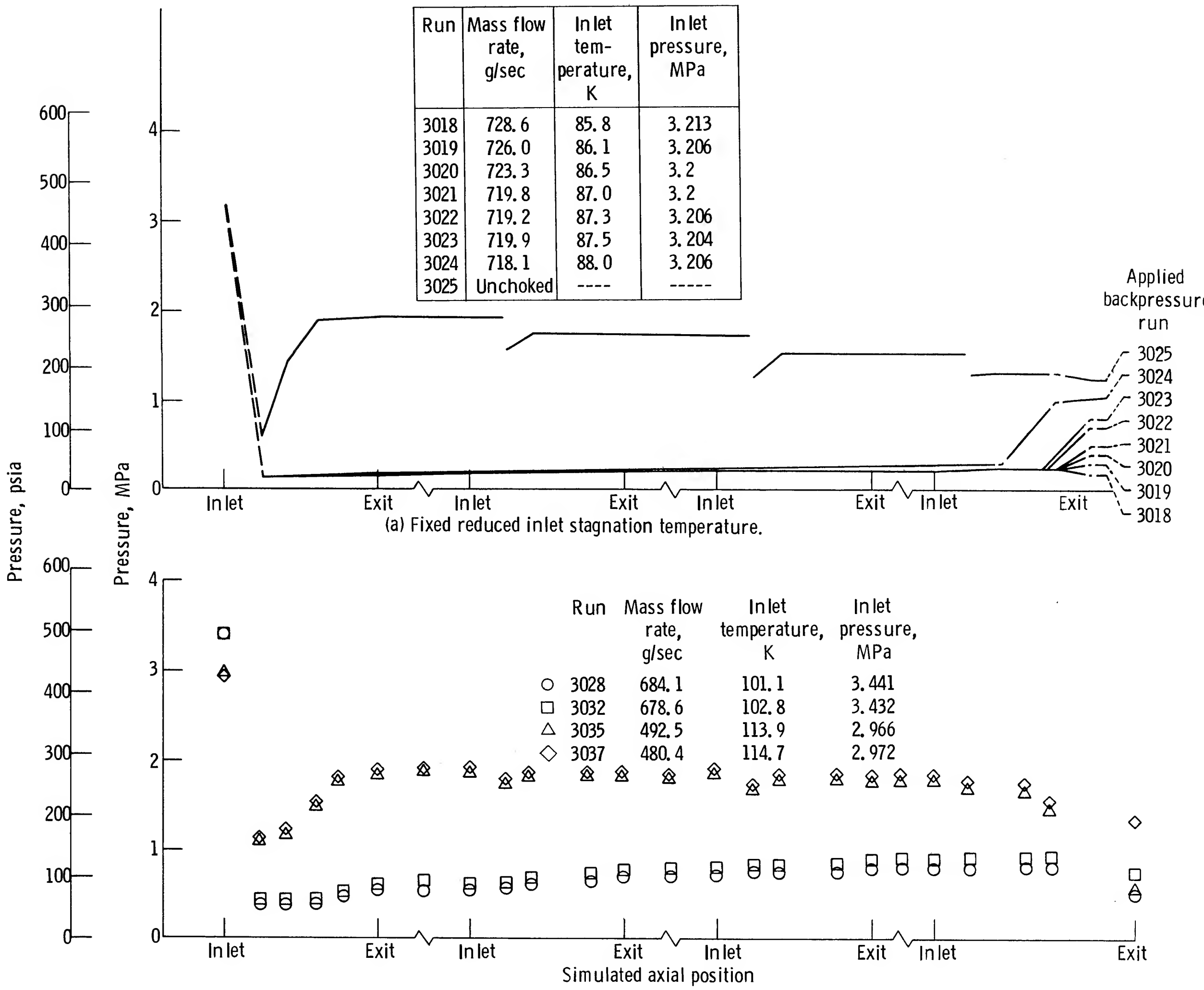
(a) Reduced inlet stagnation temperature, $T_{R,0}$ = 0.67 ("liquid").

(b) Variable reduced inlet stagnation temperature ("fluid").

Figure 21. - Pressure profiles for four sequential Borda inlets separated at 0.8 diameter with 1.03-centimeter (0.407-in.) spacers - simulated axial position with variable reduced inlet stagnation temperature.

will serve as a guide. In appendix A the case of the four sequential Borda inlets at a spacing of 0.8 diameter is discussed. Since jetting can be established at the first Borda inlet, the implication from this appendix is that jetting will continue throughout the remaining three Borda inlets, which was indeed noted experimentally. The flow rate and pressure ratio behavior are essentially defined as though the sequential configuration were only one Borda inlet.

For a gas the agreement between the analysis of



(b) Variable inlet stagnation temperature.

Figure 22. - Backpressure control pressure profiles for four sequential Borda inlets separated at 0.8 diameter with 1.03-centimeter (0.407-in.) spacers - simulated axial position.

Komotori and Mori (ref. 8) and the results presented herein indicates the direct applicability of axisymmetric results to the concentric labyrinth seal geometry, provided the proper similarity rules are followed.

Summary of Results

Choked flow rate and pressure profile data for four axially aligned, sequential Borda inlet configurations separated by spacers of 0.8 and 30 diameters have been taken and studied.

Analytic modeling is complex and an extensive effort will be required. However, a simplistic model of the 30-diameter-separation case currently being developed appears to give reasonable agreement with a limited set of gas and liquid data. Furthermore agreement with the labyrinth seal analysis of Komotori and Mori for the limiting case of a perfect gas indicates that axisymmetric results can be applied to axisymmetric annular passage flows of labyrinth seals. Implications drawn from the model appear to apply to the 0.8-diameter-separation case.

In either case it was found that, for preliminary prediction purposes, a flow coefficient plot as a function of reduced temperature could be used. However, such practice adds little to the understanding of flow details.

The deviations with pressure are not yet explained. At a separation of 30 diameters the pressure profiles within each of the four sequential inlets drop sharply

at the entrance, followed by a recovery. The exception is the last Borda inlet, where the pressure profile at low fluid temperatures and high pressures can be flat. Such a flat profile is indicative of fluid jetting.

At a separation of 0.8 diameter and at lower fluid temperatures, fluid jetting through all four sequential Borda inlets was prevalent, with choking controlled at the entrance of the first Borda inlet. Even for gas flows the pressure dropped very sharply at the entrance of the first Borda and at the exit of the last Borda, to the point of being nearly choked at either place. Application of various backpressures significantly higher then the pressures within the four sequential Borda inlets did not alter fluid jetting.

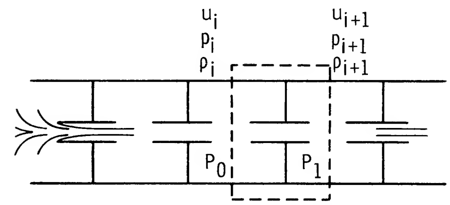
These results agree with previously published data for jetting in tubes with sharp-edge-orifice or Borda-type inlets. They are also in qualitative agreement with water table flow visualization studies used to delineate regions of fluid stability and instability, although stability was not studied as a part of this report.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, August 26, 1980

Appendix A

Example of Analysis—An Analysis of Sequential Inlet Flow

The flow process is neither steady, adiabatic, nor frictionless, as described in the text. However, if we simply ignore these problems, the governing equations for the i^{th} inlet, see sketch and figure 10, can be written as (ref. 7):



Jetting effects in sequential Borda inlets

Continuity $$\frac{\partial \rho u_l}{\partial x_l} = 0 \quad \text{(A1)}$$

Momentum $$\frac{\partial \rho u_l u_j}{\partial x_j} - \frac{\partial p}{\partial x_l} = 0 \quad \text{(A2)}$$

Energy $$\frac{\partial}{\partial x_l} \rho u_l H_0 = 0 \quad \text{(A3)}$$

where

$$H_0 = H + \frac{1}{2} u_l u_l \quad \text{(A4)}$$

State $$p = p(\rho, H, x_\alpha) \quad \text{(A5)}$$

Similarity (extended van der Waals one-fluid model for corresponding states)

$$Z_m(T, V, x_\alpha) = Z_0\left(\frac{V}{h}, \frac{T}{f}\right)$$

$$g_m(V, T, x_\alpha) = f g_0\left(\frac{V}{h}, \frac{T}{f}\right) + RT\left(\sum_{x_\alpha} x_\alpha \ln x_\alpha - \ln h\right) \quad \text{(A6)}$$

where

$$\left.\begin{aligned} h &= \sum_\alpha \sum_\beta x_\alpha x_\beta h_{\alpha\beta,0} \\ fh &= \sum_\alpha \sum_\beta x_\alpha x_\beta f_{\alpha\beta,0} h_{\alpha\beta,0} \end{aligned}\right\} \quad \text{(A7)}$$

$$\left.\begin{aligned} f_{\alpha\alpha,0} &= \left(\frac{T^c_{\alpha\alpha}}{T^c_0}\right)\theta_{\alpha\alpha,0} \\ h_{\alpha\alpha,0} &= \left(\frac{V^c_{\alpha\alpha}}{T^c_0}\right)\phi_{\alpha\alpha,0} \end{aligned}\right\} \quad \text{(A8)}$$

Isentropic restraint

$$T dS_i = dH - \frac{dp}{\rho} = 0 \qquad i = 1, n \quad \text{(A9)}$$

Isobaric restraint

$$S_{i+1} = S(\mathrm{p_i}, \mathrm{H_0}) \qquad i = 1, n \quad \text{(A10)}$$

Choking constraint

$$\mathrm{G}^2_{max} = \rho^2\left(\frac{dp}{d\rho}\right)_e = \frac{2}{V^2}\int_{p_e}^{p_0} V dp \quad \text{(A11)}$$

It appears that at the 30-diameter separation choking can occur at the entrance or exit of the last ($i=n$) of the sequential inlets. At the 0.8-diameter separation choking can occur at the inlet of the first ($i=1$) inlet of the sequential inlets or at the exit of the last ($i=n$) inlet. The details of the choking constraint, at a fixed position, for flows with change of phase are quite complex and, although used herein, will not be repeated at this time; see reference 11 for further details.

Furthermore, if one isolates an inlet (one section of fig. 4 or 7) and forms it into a blackbox, the conservation equations yield the isentropic expansion restraint

$$\left.\begin{aligned} dH_0 &= dH + d\frac{u^2}{2} \\ dp + \rho d\frac{u^2}{2} &= 0 \end{aligned}\right\} \qquad \text{(A12)}$$

or

$$\frac{dp}{\rho} - dH = 0$$

Thus we need only consider an isentropic process, and from the momentum equation we find

$$u_{i+1}^2 - u_i^2 = 2\int_{p_{i+1}}^{p_i} \frac{dp}{\rho} \qquad \text{(A13)}$$

Consider now the following cases:

(1) When $u_{i+1} >> u_i$ or u_{i-0}, the mass flux across the i[th] inlet becomes

$$G^2 = (\rho_{i+1} u_{i+1})^2 = 2\rho_{i+1}^2 \int_{p_{i+1}}^{p_i} \frac{dp}{\rho} \qquad \text{(A14)}$$

(2) When $u_{i+1} \sim u_i$ or $u_i \rightarrow u_{i+1}$, $p_{i+1} \rightarrow p_i$ and jetting can occur, provided the jet has been established elsewhere in the system and

$$G^2 \rightarrow G_{max}^2 = \rho^2 \left(\frac{dp}{d\rho}\right)_e \qquad \text{(A15)}$$

(3) For plug flow continuity, $\dot{w} = \rho_i u_i A_i = \rho_{i+1} u_{i+1} A_{i+1}$, the mass flux becomes

$$G^2 = \frac{2\rho_{i+}^2}{\left[1 - (\rho_{i+1} A_{i+1}/\rho_i A_i)^2\right]} \int_{p_{i+1}}^{p_i} \frac{dp}{\rho} \qquad \text{(A16)}$$

Again, consider two cases: (a) when $A_i >> A_{i+1}$, case (1) above results; and (b) when $(A_{i+1}\rho_{i+1} \rightarrow \rho_i A_i)$, it leads to case (2).

(4) In jetting data (refs. 3, 4, and 13) $p_{i+1} > p_i$, and it follows that $u_{i+1} < u_i$ and that the system functions as a diffuser.

The same results are achieved with enthalpy as the independent variable; from the energy equation it follows that

$$u_{i+1}^2 - u_i^2 = 2(H_0 - H_{i+1}) = 2\int_{p_{i+1}}^{p_i} \frac{dp}{\rho} \qquad \text{(A17)}$$

The enthalpy relation is used for the preliminary calculations herein.

In this report we use the simplified form of van der Waals corresponding-states principle since we only have data for fluid nitrogen.

$$\left.\begin{aligned} \theta_{\alpha\alpha,0} &= 1 \\ \phi_{\alpha\alpha,0} &= 1 \\ f = T_R &= \frac{T}{T_c} \\ P_R &= \frac{P}{P_c} \\ h = V_R &= \frac{V}{V_c} \end{aligned}\right\} \qquad \text{(A18)}$$

and

$$G_R = \frac{G}{G^*}$$

All thermophysical properties were calculated by using the computer code GASP (ref. 14).

Appendix B

Symbols

A	area
C_F	flow coefficient
f	scale function, temperature
G	mass flow rate
G^*	flow normalizing parameter, 6010 g/cm^2 sec for nitrogen, $\sqrt{p_c \rho_c / Z_c}$
g	configurational free energy
H	enthalpy
h	scale function for specific volume
p	pressure
R	gas constant
S	entropy
T	temperature
u	velocity
V	specific volume
X	pressure ratio
x	coordinate
x_α	mole fraction of species α
Z	compressibility, PV/RT
ρ	density, $1/V$

Subscripts:

c	thermodynamic critical
$calc$	calculated
e	exit
exp	experimental
i	i^{th} sequential inlet
j	coordinate index
m	mixture
$\alpha\beta$	interrelation between fluid α and fluid β
R	reduced by normalizing parameter
0	stagnation, or reference fluid

Superscript:

c	thermodynamic critical

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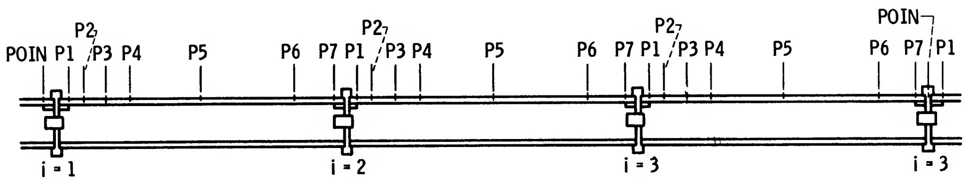
TABLE I. - DATA FOR FOUR SEQUENTIAL, AXIALLY ALIGNED BORDA INLET

TUBES - 30-DIAMETER SPACING, INSTRUMENTED SPACERS



RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
	BORDA INLET AND SPACER	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	P6 MPA	P7 MPA
3051	585.0	85.9	5.105	1.494	0.544	0.680			
	1	5.12	4.10	4.10	4.09	4.13	4.18	4.19	4.20
	2		3.06	3.06	3.06	3.09	3.15	3.15	3.15
	3		2.03	2.04	2.03	2.05	2.12	2.12	2.11
	4	0.19	0.23						
3052	526.5	85.8	4.193	1.227	0.489	0.679			
	1	4.19	3.35	3.35	3.35	3.38	3.42	3.42	3.43
	2		2.51	2.51	2.51	2.53	2.58	2.58	2.58
	3		1.66	1.67	1.66	1.69	1.75	1.75	1.74
	4	0.19	0.18						
3053	453.7	85.9	3.188	0.933	0.422	0.680			
	1	3.18	2.55	2.55	2.55	2.57	2.60	2.60	2.61
	2		1.92	1.92	1.92	1.93	1.97	1.97	1.97
	3		1.29	1.29	1.29	1.30	1.35	1.35	1.35
	4	0.20	0.18						
3054	407.0	85.4	2.606	0.763	0.378	0.676			
	1	2.58	2.08	2.09	2.09	2.09	2.12	2.12	2.12
	2		1.58	1.58	1.58	1.58	1.61	1.62	1.62
	3		1.06	1.07	1.06	1.08	1.12	1.12	1.11
	4	0.18	0.18						
3055	353.7	85.3	2.029	0.594	0.329	0.675			
	1	2.00	1.62	1.62	1.63	1.63	1.65	1.65	1.65
	2		1.24	1.24	1.24	1.24	1.26	1.26	1.26
	3		0.85	0.85	0.85	0.86	0.90	0.90	0.89
	4	0.18	0.18						
3056	304.0	85.4	1.581	0.463	0.283	0.676			
	1	1.55	1.26	1.26	1.27	1.27	1.29	1.29	1.29
	2		0.98	0.98	0.98	0.98	0.99	1.00	1.00
	3		0.68	0.69	0.68	0.69	0.73	0.73	0.71
	4	0.23	0.19						

TABLE I. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	P6 MPA	P7 MPA
3057	245.8	85.7	1.137	0.333	0.228	0.679			
	1	1.11	0.91	0.91	0.93	0.91	0.93	0.93	0.93
	2		0.72	0.72	0.72	0.72	0.73	0.73	0.73
	3		0.52	0.53	0.52	0.52	0.56	0.56	0.54
	4	0.19	0.21						
3058	383.7	126.3	5.349	1.565	0.357	1.000			
	1	5.38	4.73	4.73	4.71	4.75	4.78	4.80	4.80
	2		4.05	4.06	4.05	4.06	4.11	4.10	4.11
	3		3.35	3.36	3.35	3.37	3.41	3.41	3.41
	4	1.90	0.37						
3059	299.8	126.9	4.335	1.269	0.279	1.005			
	1	4.35	3.91	3.92	3.90	3.93	3.95	3.96	3.96
	2		3.46	3.46	3.46	3.47	3.50	3.49	3.50
	3		2.99	2.99	2.99	2.99	3.02	3.02	3.02
	4	1.55	0.30						
3060	243.0	125.8	3.596	1.052	0.226	0.996			
	1	3.61	3.30	3.31	3.30	3.31	3.33	3.33	3.33
	2		2.98	2.98	2.98	2.98	3.01	3.00	3.01
	3		2.49	2.50	2.49	2.49	2.53	2.53	2.53
	4	1.31	0.25						
3061	133.5	125.3	3.048	0.892	0.124	0.992			
	1	3.05	2.76	2.78	2.77	2.78	2.79	2.79	2.79
	2		2.42	2.42	2.42	2.42	2.44	2.44	2.44
	3		1.97	1.98	1.97	1.98	2.01	2.00	2.00
	4	0.83	0.15						
3062	137.9	126.9	3.172	0.928	0.128	1.005			
	1	3.19	2.89	2.90	2.89	2.91	2.91	2.92	2.92
	2		2.53	2.54	2.53	2.54	2.56	2.56	2.56
	3		2.06	2.07	2.06	2.06	2.10	2.10	2.09
	4	0.85	0.16						

TABLE I. - Continued.

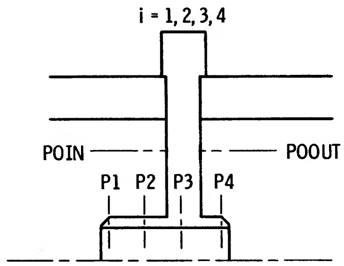
RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	P6 MPA	P7 MPA
3063	84.7	125.4	2.158	0.632	0.079	0.993			
	1	2.15	1.93	1.93	1.93	1.93	1.94	1.94	1.95
	2		1.66	1.66	1.66	1.66	1.68	1.68	1.68
	3		1.33	1.33	1.33	1.33	1.37	1.37	1.35
	4	0.56	0.13						
3064	83.1	126.8	2.245	0.657	0.082	1.004			
	1	2.24	2.00	2.02	2.02	2.02	2.02	2.02	2.02
	2		1.73	1.73	1.73	1.73	1.75	1.75	1.75
	3		1.38	1.39	1.38	1.38	1.42	1.42	1.41
	4	0.58	0.13						
3065	465.3	114.0	4.643	1.359	0.432	0.903			
	1	4.66	3.84	3.86	3.84	3.86	3.91	3.92	3.93
	2		3.02	3.02	3.02	3.04	3.09	3.08	3.09
	3		2.17	2.17	2.17	2.19	2.25	2.25	2.24
	4	0.70	0.44						
3066	383.4	114.4	3.516	1.029	0.356	0.906			
	1	3.51	2.95	2.95	2.95	2.97	2.99	3.00	3.00
	2		2.38	2.38	2.38	2.39	2.42	2.42	2.42
	3		1.75	1.75	1.75	1.76	1.81	1.81	1.81
	4	0.73	0.40						
3067	302.0	113.8	2.785	0.815	0.281	0.901			
	1	2.80	2.44	2.44	2.44	2.45	2.46	2.47	2.46
	2		2.08	2.08	2.08	2.09	2.10	2.10	2.11
	3		1.69	1.69	1.69	1.69	1.73	1.73	1.72
	4	1.12	0.32						
3068	201.6	113.4	2.037	0.596	0.187	0.898			
	1	2.02	1.86	1.86	1.87	1.87	1.87	1.87	1.88
	2		1.69	1.70	1.69	1.69	1.70	1.71	1.71
	3		1.48	1.49	1.48	1.48	1.51	1.51	1.50
	4	0.98	0.21						

TABLE I. - Concluded.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	P6 MPA	P7 MPA
3070	32.4	214.8	1.274	0.373	0.030	1.701			
	1	1.25	1.11	1.11	1.13	1.11	1.13	1.12	1.13
	2		0.94	0.95	0.95	0.97	0.95	0.97	0.96
	3		0.76	0.77	0.76	0.77	0.80	0.80	0.78
	4	0.26	0.12						
3071	53.0	221.5	2.087	0.611	0.049	1.754			
	1	2.08	1.86	1.86	1.86	1.86	1.87	1.86	1.87
	2		1.60	1.60	1.60	1.60	1.61	1.62	1.61
	3		1.27	1.27	1.27	1.28	1.31	1.31	1.30
	4	0.47	0.12						
3072	93.2	232.3	3.705	1.084	0.087	1.839			
	1	3.72	3.32	3.33	3.32	3.33	3.35	3.36	3.36
	2		2.86	2.86	2.86	2.86	2.89	2.89	2.89
	3		2.27	2.28	2.28	2.29	2.32	2.32	2.32
	4	0.82	0.16						

TABLE II. - DATA FOR FOUR SEQUENTIAL, AXIALLY ALIGNED BORDA INLET

TUBES - 30-DIAMETER SPACING, UNINSTRUMENTED SPACERS



RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA INLET		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2824	33.3	293.0	1.544	0.452	0.031	2.320	
	1	1.51	1.22	1.30	1.33	1.35	1.35
	2	1.37	1.01	1.12	0.00	1.20	1.20
	3	1.18	0.72	0.86	0.92	0.94	0.93
	4	0.97	0.19	0.37	0.34	0.35	0.12
2825	57.8	289.0	2.634	0.771	0.054	2.288	
	1	2.62	2.12	2.23	2.30	2.33	2.33
	2	2.37	1.75	1.93	0.00	2.05	2.05
	3	2.04	1.26	1.50	1.59	1.62	1.62
	4	1.66	0.32	0.62	0.59	0.59	0.13
2826	82.1	286.0	3.714	1.087	0.076	2.264	
	1	3.73	3.00	3.15	3.26	3.31	3.31
	2	3.37	2.48	2.74	0.00	2.89	0.00
	3	2.89	1.80	2.13	2.26	2.31	2.29
	4	2.34	0.44	0.87	0.93	0.82	0.16
2827	109.0	286.0	4.918	1.439	0.101	2.264	
	1	4.95	3.98	4.18	4.35	4.39	4.41
	2	4.48	3.29	3.64	3.78	3.84	3.84
	3	3.84	2.39	2.82	3.00	3.04	3.04
	4	3.10	0.57	1.14	1.06	1.09	0.19
2828	134.0	285.0	5.995	1.754	0.125	2.257	
	1	6.06	4.86	5.10	5.31	5.35	5.38
	2	5.47	4.02	4.44	4.60	4.67	4.68
	3	4.69	2.91	3.43	3.66	3.71	3.71
	4	3.78	0.68	1.38	1.28	1.33	0.22
2829	571.0	86.0	4.968	1.454	0.531	0.681	
	1	4.98	3.11	3.55	3.88	3.91	3.96
	2	4.07	2.08	2.66	2.95	3.00	3.02
	3	3.06	1.07	1.63	1.95	2.00	1.98
	4	2.08	0.19	0.18	0.20	0.21	0.20

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2830	456.0	86.0	3.317	0.971	0.424	0.681	
	1	3.29	2.09	2.38	2.58	2.62	2.63
	2	2.71	1.42	1.80	0.00	2.03	2.04
	3	2.05	0.76	1.12	1.33	1.37	1.35
	4	1.42	0.20	0.20	0.21	0.21	0.21
2831	387.0	86.0	2.447	0.716	0.360	0.681	
	1	2.42	1.55	1.76	1.90	1.93	1.93
	2	2.00	1.06	1.35	1.53	1.51	1.51
	3	1.52	0.59	0.86	1.00	1.03	1.02
	4	1.07	0.20	0.19	0.23	0.20	0.20
2832	300.0	86.0	1.575	0.461	0.279	0.681	
	1	1.53	1.02	1.15	1.22	1.24	1.24
	2	1.28	0.72	0.89	1.01	1.00	1.00
	3	1.00	0.42	0.59	0.68	0.70	0.70
	4	0.73	0.21	0.20	0.21	0.20	0.20
2833	737.0	86.0	8.283	2.424	0.685	0.681	
	1	8.35	5.19	5.91	6.51	6.55	6.65
	2	6.84	3.45	4.44	0.00	5.00	5.02
	3	5.11	1.74	2.67	3.21	3.30	3.29
	4	3.42	0.20	0.19	0.22	0.24	0.19
2834	643.0	86.0	6.400	1.873	0.598	0.681	
	1	6.43	4.00	4.56	5.01	5.05	5.12
	2	5.26	2.66	3.42	0.00	3.86	3.86
	3	3.95	1.37	2.11	2.50	2.56	2.55
	4	2.66	0.21	0.20	0.40	0.24	0.21
2835	25.3	260.0	1.490	0.436	0.024	2.059	
	1	1.47	1.18	1.26	1.30	1.30	1.31
	2	1.32	0.98	1.08	1.13	1.12	1.13
	3	1.14	0.71	0.84	0.89	0.90	0.90
	4	0.91	0.17	0.35	0.37	0.34	0.12

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2836	49.5	260.0	2.250	0.658	0.046	2.059	
	1	2.24	1.80	1.92	1.99	1.98	2.00
	2	2.02	1.49	1.65	1.72	1.71	1.72
	3	1.74	1.09	1.29	1.36	1.38	1.37
	4	1.40	0.26	0.53	0.48	0.51	0.12
2837	82.0	264.0	3.676	1.076	0.076	2.090	
	1	3.69	2.95	3.14	3.27	3.26	3.29
	2	3.33	2.44	2.71	2.82	2.82	2.84
	3	2.86	1.79	2.11	2.24	2.26	2.24
	4	2.29	0.42	0.85	0.78	0.82	0.15
2838	149.0	275.0	6.520	1.908	0.139	2.177	
	1	6.59	5.26	5.58	5.83	5.82	5.86
	2	5.94	4.36	4.82	5.02	5.03	5.05
	3	5.10	3.17	3.73	3.98	4.01	3.99
	4	4.06	0.71	1.49	1.38	1.44	0.23
2839	25.5	264.0	1.119	0.327	0.024	2.090	
	1	1.10	0.89	0.94	0.98	0.97	0.96
	2	0.98	0.73	0.80	0.84	0.83	0.84
	3	0.85	0.53	0.62	0.67	0.67	0.67
	4	0.68	0.13	0.26	0.24	0.26	0.12
2840	38.5	266.0	1.654	0.493	0.036	2.106	
	1	1.66	1.34	1.43	1.49	1.47	1.49
	2	1.50	1.11	1.23	1.28	1.27	1.28
	3	1.29	0.80	0.95	1.02	1.02	1.02
	4	1.04	0.19	0.39	0.36	0.38	0.11
2841	64.1	270.0	2.804	0.821	0.060	2.138	
	1	2.81	2.25	2.40	2.50	2.48	2.50
	2	2.53	1.86	2.07	2.14	2.14	2.16
	3	2.18	1.36	1.61	1.71	1.72	1.71
	4	1.74	0.32	0.66	0.70	0.63	0.13

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2842	127.0	275.0	5.546	1.623	0.118	2.177	
	1	5.60	4.48	4.75	4.96	4.94	4.99
	2	5.05	3.71	4.10	4.26	4.27	4.30
	3	4.34	2.70	3.18	3.38	3.41	3.40
	4	3.46	0.61	1.27	1.18	1.23	0.20
2843	127.0	275.0	5.515	1.614	0.118	2.177	
	1	5.57	4.45	4.73	4.93	4.91	4.96
	2	5.02	3.69	4.07	4.35	4.22	4.27
	3	4.31	2.69	3.15	3.36	3.40	3.38
	4	3.45	0.61	1.27	1.17	1.22	0.20
2844	127.0	273.0	5.501	1.610	0.118	2.162	
	1	5.55	4.44	4.72	4.92	4.90	4.95
	2	5.01	3.68	4.06	4.22	4.20	4.26
	3	4.30	2.68	3.15	3.35	3.39	3.38
	4	3.44	0.61	1.27	1.26	1.22	0.20
2845	126.0	273.0	5.490	1.607	0.117	2.162	
	1	5.54	4.43	4.71	4.91	4.89	4.93
	2	5.00	3.66	4.05	4.22	4.19	4.25
	3	4.29	2.67	3.15	3.35	3.38	3.37
	4	3.43	0.61	1.26	1.17	1.22	0.20
2846	23.8	286.0	1.089	0.319	0.022	2.264	
	1	1.06	0.86	0.92	0.94	0.94	0.95
	2	0.95	0.71	0.78	0.81	0.81	0.82
	3	0.82	0.51	0.61	0.65	0.66	0.65
	4	0.66	0.12	0.25	0.20	0.25	0.11
2847	36.6	282.0	1.655	0.484	0.034	2.233	
	1	1.63	1.31	1.40	1.44	1.44	1.45
	2	1.47	1.09	1.20	1.24	1.25	1.25
	3	1.26	0.80	0.93	1.00	1.00	1.00
	4	1.02	0.19	0.39	0.32	0.37	0.11

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2848	27.1	283.0	1.234	0.361	0.025	2.241
	1	1.21	0.98	1.04	1.07	1.07	1.07
	2	1.09	0.80	0.89	0.93	0.93	0.93
	3	0.94	0.59	0.69	0.74	0.74	0.74
	4	0.75	0.14	0.29	0.23	0.28	0.11
2849	27.3	283.0	1.236	0.362	0.025	2.241
	1	1.21	0.98	1.05	1.07	1.07	1.08
	2	1.09	0.81	0.89	0.93	0.93	0.93
	3	0.94	0.59	0.69	0.74	0.75	0.74
	4	0.76	0.14	0.29	0.23	0.28	0.12
2850	27.4	282.0	1.240	0.363	0.025	2.233
	1	1.22	0.99	1.05	1.08	1.08	1.08
	2	1.09	0.81	0.89	0.93	0.93	0.93
	3	0.95	0.59	0.70	0.74	0.75	0.74
	4	0.76	0.15	0.29	0.23	0.28	0.11
2851	39.8	281.0	1.788	0.523	0.037	2.225
	1	1.77	1.43	1.53	1.57	1.57	1.58
	2	1.59	1.18	1.30	1.35	1.35	1.36
	3	1.38	0.86	1.02	1.08	1.09	1.08
	4	1.11	0.21	0.42	0.35	0.40	0.12
2852	29.1	282.0	1.316	0.385	0.027	2.233
	1	1.29	1.05	1.12	1.15	1.15	1.15
	2	1.16	0.86	0.95	0.99	0.99	1.00
	3	1.00	0.63	0.74	0.79	0.80	0.00
	4	0.81	0.15	0.31	0.25	0.31	0.34
2853	33.2	279.0	1.492	0.437	0.031	2.209
	1	1.47	1.19	1.27	1.31	1.31	1.31
	2	1.33	0.98	1.09	1.13	1.13	1.13
	3	1.15	0.69	0.84	0.90	0.91	0.00
	4	0.92	0.18	0.35	0.29	0.35	0.38

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2854	25.6	277.0	1.150	0.337	0.024	2.193	
	1	1.13	0.91	0.98	1.00	1.00	1.00
	2	1.02	0.75	0.83	0.86	0.86	0.87
	3	0.88	0.55	0.64	0.69	0.70	0.00
	4	0.71	0.13	0.27	0.22	0.27	0.30
2855	18.5	277.0	0.632	0.243	0.017	2.193	
	1	0.61	0.66	0.71	0.72	0.72	0.72
	2	0.73	0.54	0.59	0.63	0.62	0.62
	3	0.63	0.39	0.46	0.49	0.50	0.00
	4	0.51	0.09	0.20	0.16	0.20	0.21
2856	25.7	284.0	1.169	0.342	0.024	2.249	
	1	1.13	0.92	0.99	1.01	1.01	1.02
	2	1.02	0.76	0.84	0.87	0.87	0.87
	3	0.89	0.55	0.65	0.70	0.70	0.70
	4	0.71	0.13	0.28	0.22	0.28	0.30
2857	26.2	282.0	1.186	0.347	0.024	2.233	
	1	1.15	0.93	1.00	1.02	1.02	1.03
	2	1.04	0.77	0.84	0.88	0.89	0.89
	3	0.90	0.56	0.66	0.71	0.71	0.71
	4	0.72	0.14	0.28	0.22	0.28	0.31
2858	27.0	280.0	1.219	0.357	0.025	2.217	
	1	1.19	0.96	1.03	1.06	1.05	1.06
	2	1.07	0.79	0.87	0.91	0.91	0.91
	3	0.93	0.58	0.68	0.73	0.73	0.73
	4	0.74	0.14	0.29	0.23	0.29	0.32
2859	35.4	278.0	1.584	0.464	0.033	2.201	
	1	1.55	1.25	1.34	1.38	1.38	1.39
	2	1.40	1.03	1.15	1.19	1.19	1.20
	3	1.21	0.75	0.89	0.95	0.96	0.95
	4	0.98	0.18	0.37	0.31	0.37	0.41

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2860	40.4	278.0	2.066	0.605	0.043	2.201	
	1	2.04	1.64	1.76	1.82	1.82	1.82
	2	1.84	1.36	1.51	1.57	1.57	1.58
	3	1.60	1.00	1.18	1.25	1.26	1.25
	4	1.28	0.24	0.48	0.41	0.48	0.53
2861	56.1	276.0	2.342	0.685	0.052	2.185	
	1	2.33	1.87	2.00	2.06	2.06	2.07
	2	2.10	1.55	1.71	1.78	1.78	1.79
	3	1.81	1.13	1.33	1.42	1.43	1.42
	4	1.45	0.27	0.55	0.47	0.54	0.60
2862	0.9	291.0	2.577	0.754	0.001	2.304	
	1	2.58	2.59	2.58	2.58	2.58	2.58
	2	2.58	2.58	2.58	2.59	2.58	2.58
	3	2.58	2.58	2.58	2.58	2.58	2.58
	4	2.58	2.58	2.58	2.58	2.58	2.58
2863	24.1	280.0	1.087	0.318	0.022	2.217	
	1	1.05	0.85	0.91	0.94	0.93	0.94
	2	0.95	0.70	0.78	0.81	0.80	0.81
	3	0.82	0.51	0.60	0.64	0.65	0.65
	4	0.66	0.12	0.25	0.20	0.25	0.12
2864	39.9	278.0	1.779	0.521	0.037	2.201	
	1	1.75	1.41	1.51	1.55	1.55	1.57
	2	1.58	1.16	1.30	1.35	1.34	1.35
	3	1.37	0.85	1.01	1.07	1.08	1.08
	4	1.09	0.21	0.42	0.35	0.40	0.12
2866	135.0	287.0	6.030	1.765	0.125	2.272	
	1	6.08	4.87	5.16	5.38	5.39	5.42
	2	5.49	4.03	4.46	4.64	4.65	4.66
	3	4.72	2.93	3.44	3.68	3.71	3.69
	4	3.77	0.66	1.38	1.25	1.33	0.21

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2868	30.8	284.0	1.400	0.410	0.029	2.249	
	1	1.38	1.11	1.19	1.22	1.22	1.22
	2	1.24	0.91	1.01	1.05	1.05	1.06
	3	1.07	0.67	0.79	0.84	0.85	0.84
	4	0.86	0.16	0.33	0.27	0.32	0.11
2869	81.3	288.0	3.659	1.071	0.076	2.280	
	1	3.67	2.95	3.13	3.24	3.24	3.27
	2	3.31	2.44	2.69	2.80	2.81	2.82
	3	2.86	1.78	2.10	2.23	2.25	2.24
	4	2.29	0.42	0.85	0.75	0.81	0.15
2870	4.6	289.0	3.920	1.147	0.004	2.288	
	1	3.96	3.97	3.94	3.95	3.95	3.95
	2	3.97	3.97	3.95	3.95	3.95	3.95
	3	3.96	3.96	3.95	3.95	3.94	3.94
	4	3.93	3.94	3.93	3.95	3.93	3.93
2871	649.0	86.1	6.310	1.847	0.603	0.682	
	1	6.33	3.91	4.51	4.95	4.95	5.03
	2	5.16	2.55	3.35	3.73	3.73	3.75
	3	3.87	1.31	2.03	2.42	2.49	2.46
	4	2.57	0.15	0.15	0.14	0.18	0.17
2872	516.0	86.3	4.114	1.204	0.480	0.683	
	1	4.11	2.55	2.95	3.22	3.23	3.23
	2	3.35	1.69	2.21	2.44	2.45	2.46
	3	2.53	0.89	1.35	1.61	1.64	1.63
	4	1.70	0.16	0.17	0.15	0.18	0.18
2873	404.0	85.8	2.600	0.761	0.375	0.679	
	1	2.58	1.62	1.88	2.04	2.04	2.06
	2	2.11	1.09	1.41	1.55	1.55	1.56
	3	1.61	0.61	0.89	1.05	1.06	1.06
	4	1.11	0.16	0.17	0.15	0.18	0.18

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
BORDA INLET		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA

RUN / BORDA INLET	MASS FLOW G/S	TIN K / POIN MPA	PIN MPA / P1 MPA	PR / P2 MPA	GR / P3 MPA	TR / P4 MPA	POOUT MPA
2874	351.0	86.1	2.030	0.594	0.326	0.682	
	1	2.00	1.28	1.48	1.59	1.59	1.61
	2	1.64	0.88	1.11	1.22	1.22	1.23
	3	1.26	0.51	0.72	0.84	0.86	0.85
	4	0.89	0.17	0.18	0.16	0.18	0.19
2875	294.0	86.3	1.509	0.442	0.273	0.683	
	1	1.46	0.95	1.11	1.18	1.18	1.19
	2	1.22	0.68	0.84	0.91	0.92	0.93
	3	0.95	0.42	0.57	0.65	0.66	0.66
	4	0.68	0.18	0.18	0.17	0.19	0.19
2876	263.0	86.6	1.260	0.369	0.244	0.686	
	1	1.22	0.82	0.93	1.00	1.00	1.00
	2	1.02	0.59	0.72	0.78	0.78	0.79
	3	0.81	0.37	0.49	0.56	0.57	0.57
	4	0.59	0.18	0.19	0.17	0.19	0.19
2877	641.0	87.0	6.209	1.817	0.596	0.689	
	1	6.23	3.36	4.46	4.89	4.89	4.97
	2	5.09	2.53	3.33	3.67	3.69	3.71
	3	3.82	1.31	2.00	2.41	2.46	2.43
	4	2.53	0.17	0.17	0.16	0.20	0.19
2878	606.0	99.3	6.217	1.819	0.563	0.786	
	1	6.24	3.94	4.51	4.93	4.93	5.02
	2	5.13	2.64	3.41	3.75	3.77	3.78
	3	3.90	1.44	2.13	2.52	2.57	2.55
	4	2.64	0.12	0.33	0.31	0.40	0.33
2879	496.0	99.4	4.330	1.267	0.461	0.787	
	1	4.32	4.00	3.15	3.44	3.44	3.49
	2	3.56	1.87	2.39	2.63	2.64	2.65
	3	2.73	1.07	1.53	1.80	1.83	1.82
	4	1.89	0.12	0.34	0.32	0.39	0.33

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
2880	409.0	99.3	3.070	0.898	0.380	0.786
2881	314.7	98.6	1.940	0.568	0.292	0.781
2882	232.4	98.4	1.298	0.380	0.216	0.779
2883	471.0	123.0	6.165	1.804	0.438	0.974
2884	379.0	121.9	4.666	1.366	0.352	0.965
2885	285.0	120.5	3.405	0.996	0.265	0.954

RUN	BORDA INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2880	1	3.05	0.00	2.26	2.44	2.44	2.48
	2	2.53	1.38	1.73	1.89	1.90	1.91
	3	1.96	1.20	1.13	1.32	1.35	1.33
	4	1.39	0.11	0.33	0.31	0.36	0.31
2881	1	1.91	0.00	1.45	1.55	1.55	1.57
	2	1.60	0.92	1.13	1.22	1.22	1.24
	3	1.26	0.61	0.65	0.85	0.90	0.89
	4	0.92	0.29	0.30	0.27	0.32	0.27
2882	1	1.26	0.00	1.02	1.06	1.06	1.07
	2	1.09	0.72	0.82	0.88	0.88	0.89
	3	0.91	0.54	0.55	0.61	0.67	0.67
	4	0.69	0.34	0.35	0.33	0.34	0.23
2883	1	6.20	0.00	4.86	5.20	5.20	5.26
	2	5.35	3.43	4.02	4.29	4.30	4.31
	3	4.40	2.50	2.98	3.32	3.36	3.33
	4	3.42	1.55	1.65	1.85	1.76	0.46
2884	1	4.68	0.00	3.79	4.01	4.01	4.05
	2	4.11	2.84	3.22	3.40	3.41	3.42
	3	3.49	2.23	2.44	2.75	2.78	2.77
	4	2.82	1.60	1.71	1.75	1.64	0.38
2885	1	3.40	0.00	2.90	3.02	3.02	3.04
	2	3.08	2.36	2.55	2.67	2.67	2.68
	3	2.72	2.01	2.11	2.27	2.30	2.29
	4	2.33	1.55	1.68	1.55	1.42	0.28

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
2886	195.0	119.0	2.481	0.726	0.181	0.942
2887	50.6	113.0	1.758	0.514	0.047	0.895
2888	49.3	111.0	1.255	0.367	0.046	0.879
2889	634.0	85.8	5.873	1.720	0.589	0.679
2890	538.0	86.0	4.329	1.267	0.500	0.681
2891	453.0	86.4	3.159	0.924	0.421	0.684

RUN	BORDA INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2886	1	2.46	2.15	2.22	2.28	2.28	2.29
	2	2.31	1.95	2.03	2.06	2.06	2.06
	3	2.09	1.62	1.71	1.74	1.74	1.73
	4	1.76	1.04	1.08	0.93	0.89	0.19
2887	1	1.73	1.54	1.60	1.60	1.59	1.60
	2	1.61	1.36	1.40	1.42	1.42	1.42
	3	1.44	1.12	1.17	1.19	1.18	1.18
	4	1.20	0.74	0.76	0.64	0.61	0.16
2888	1	1.22	0.99	1.07	1.09	1.09	1.09
	2	1.11	0.82	0.91	0.94	0.94	0.95
	3	0.96	0.60	0.71	0.76	0.76	0.76
	4	0.77	0.18	0.35	0.28	0.35	0.12
2889	1	5.89	3.64	4.20	4.62	4.62	4.69
	2	4.80	2.37	3.15	3.49	3.49	3.51
	3	3.62	1.26	1.91	2.30	2.33	2.31
	4	2.42	0.17	0.18	0.16	0.20	0.23
2890	1	4.32	2.69	3.10	3.40	3.40	3.44
	2	3.53	1.74	2.34	2.57	2.58	2.58
	3	2.66	0.95	1.42	1.69	1.73	1.71
	4	1.79	0.16	0.16	0.15	0.18	0.18
2891	1	3.13	1.97	2.27	2.48	2.48	2.51
	2	2.57	1.30	1.71	1.89	1.89	1.90
	3	1.95	0.73	1.06	1.26	1.29	1.27
	4	1.33	0.17	0.17	0.16	0.18	0.19

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PP	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2892	389.0	85.6	2.393	0.700	0.362	0.678	
	1	2.36	1.50	1.73	1.87	1.87	1.90
	2	1.94	1.01	1.31	1.44	1.44	1.44
	3	1.49	0.58	0.82	0.98	1.00	0.98
	4	1.02	0.16	0.17	0.15	0.18	0.18
2893	290.0	85.9	1.457	0.426	0.270	0.680	
	1	1.42	0.93	1.07	1.14	1.14	1.16
	2	1.18	0.65	0.82	0.89	0.89	0.90
	3	0.92	0.41	0.55	0.63	0.64	0.64
	4	0.66	0.17	0.18	0.16	0.18	0.19
2894	584.0	103.0	5.882	1.721	0.543	0.816	
	1	5.89	3.75	4.27	4.68	4.67	4.75
	2	4.86	2.49	3.29	3.60	3.60	3.62
	3	3.72	1.44	2.07	2.44	2.49	2.46
	4	2.56	0.39	0.40	0.38	0.48	0.39
2895	506.0	103.0	4.537	1.328	0.470	0.816	
	1	4.53	2.91	3.32	3.62	3.62	3.67
	2	3.75	1.97	2.55	2.80	2.80	2.81
	3	2.89	1.18	1.65	1.93	1.96	1.94
	4	2.02	0.38	0.40	0.36	0.44	0.36
2896	410.0	102.0	3.133	0.917	0.381	0.808	
	1	3.11	2.04	2.31	2.51	2.50	2.54
	2	2.59	1.42	1.80	1.95	1.96	1.98
	3	2.02	0.90	1.11	1.38	1.40	1.40
	4	1.44	0.36	0.38	0.35	0.41	0.33
2897	345.0	102.0	2.320	0.679	0.321	0.808	
	1	2.29	1.53	1.73	1.86	1.65	1.89
	2	1.92	1.10	1.36	1.47	1.47	1.49
	3	1.52	0.74	0.77	1.00	1.08	1.07
	4	1.11	0.34	0.36	0.33	0.38	0.30

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2898	232.0	102.0	1.442	0.422	0.216	0.808	
	1	1.41	1.06	1.17	1.22	1.21	1.22
	2	1.24	0.87	0.98	1.04	1.04	1.04
	3	1.06	0.70	0.71	0.80	0.83	0.83
	4	0.85	0.49	0.51	0.50	0.48	0.23
2900	342.0	126.0	4.770	1.396	0.318	0.998	
	1	4.78	3.78	4.00	4.21	4.20	4.24
	2	4.30	3.18	3.53	3.69	3.69	3.69
	3	3.75	2.66	2.85	3.11	3.14	3.13
	4	3.18	1.73	1.83	1.59	1.58	0.32
2901	281.0	127.0	4.161	1.218	0.261	1.006	
	1	4.20	3.44	3.61	3.77	3.76	3.79
	2	3.83	3.01	3.23	3.37	3.37	3.38
	3	3.42	2.50	2.75	2.87	2.87	2.86
	4	2.91	1.41	1.54	1.37	1.37	0.27
2902	233.0	126.0	3.548	1.038	0.217	0.998	
	1	3.55	3.02	3.12	3.24	3.24	3.26
	2	3.29	2.65	2.83	2.92	2.92	2.92
	3	2.96	2.16	2.29	2.42	2.45	2.44
	4	2.49	1.23	1.32	1.18	1.17	0.23
2903	183.0	126.0	3.244	0.949	0.175	0.998	
	1	3.26	2.78	2.87	2.97	2.97	2.99
	2	3.02	2.43	2.55	2.64	2.64	2.65
	3	2.69	1.95	2.06	2.17	2.18	2.18
	4	2.22	1.06	1.15	1.04	1.02	0.20
2904	173.0	126.0	3.323	0.972	0.161	0.998	
	1	3.32	2.82	2.91	3.02	3.02	3.04
	2	3.06	2.46	2.58	2.67	2.69	2.69
	3	2.73	1.95	2.09	2.19	2.22	2.22
	4	2.25	1.03	1.15	1.04	1.03	0.20

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
BORDA INLET		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2905	131.0	126.0	3.026	0.886	0.122	0.998	
	1	3.03	2.50	2.62	2.73	2.72	2.74
	2	2.77	2.11	2.31	2.40	2.40	2.40
	3	2.43	1.61	1.84	1.95	1.95	1.95
	4	1.99	0.61	0.85	0.71	0.86	0.15
2906	120.0	126.0	2.838	0.831	0.112	0.998	
	1	2.82	2.31	2.44	2.53	2.52	2.54
	2	2.57	1.94	2.12	2.21	2.21	2.22
	3	2.25	1.49	1.71	1.81	1.82	1.81
	4	1.85	0.53	0.79	0.67	0.79	0.14
2907	102.0	126.0	2.525	0.739	0.095	0.998	
	1	2.53	2.04	2.13	2.25	2.24	2.26
	2	2.29	1.70	1.88	1.95	1.95	1.96
	3	1.99	1.28	1.49	1.58	1.58	1.58
	4	1.61	0.46	0.74	0.60	0.73	0.13
2908*	66.7	126.0	1.778	0.520	0.062	0.998	
	1	1.75	1.42	1.51	1.56	1.55	1.57
	2	1.53	1.17	1.29	1.35	1.35	1.35
	3	1.38	0.86	1.01	1.08	1.09	1.08
	4	1.11	0.21	0.43	0.37	0.43	0.12
2909	175.0	164.0	5.118	1.498	0.163	1.298	
	1	5.14	4.11	4.35	4.55	4.53	4.58
	2	4.64	4.76	3.76	3.92	3.93	3.93
	3	4.00	2.49	2.91	3.11	3.15	3.13
	4	3.20	0.57	1.20	1.07	1.17	0.21
2910	124.0	169.0	3.790	1.109	0.115	1.338	
	1	3.79	3.04	3.23	3.36	3.35	3.38
	2	3.42	2.85	2.78	2.90	2.91	2.91
	3	2.95	1.84	2.16	2.31	2.33	2.32
	4	2.37	0.43	0.89	0.79	0.88	0.16

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
BORDA INLET		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA

RUN / BORDA	MASS FLOW G/S / INLET	TIN K / POIN MPA	PIN MPA / P1 MPA	PR / P2 MPA	GR / P3 MPA	TR / P4 MPA	POOUT MPA
2911	88.0	164.0	2.794	0.818	0.082	1.298	
	1	2.79	2.24	2.38	2.47	2.46	2.49
	2	2.52	1.84	2.05	2.13	2.13	2.14
	3	2.18	1.36	1.60	1.70	1.71	1.70
	4	1.74	0.32	0.66	0.57	0.64	0.14
2912	59.5	164.0	1.921	0.562	0.055	1.298	
	1	1.92	1.55	1.66	1.71	1.70	1.71
	2	1.73	1.27	1.42	1.47	1.47	1.48
	3	1.50	0.94	1.10	1.18	1.17	1.16
	4	1.18	0.22	0.46	0.39	0.43	0.12
2913	40.3	163.0	1.320	0.386	0.037	1.291	
	1	1.29	1.04	1.12	1.15	1.14	1.15
	2	1.16	0.86	0.95	0.99	0.99	0.99
	3	1.01	0.63	0.74	0.80	0.80	0.79
	4	0.81	0.15	0.31	0.26	0.29	0.12
2914	222.0	115.0	2.324	0.680	0.206	0.911	
	1	2.30	1.94	2.04	2.10	2.09	2.11
	2	2.13	1.74	1.82	1.90	1.90	1.91
	3	1.93	1.55	1.60	1.67	1.68	1.67
	4	1.70	1.13	1.20	1.04	0.96	1.29
2915	168.0	115.0	1.927	0.564	0.156	0.911	
	1	1.90	1.69	1.75	1.78	1.77	1.78
	2	1.79	1.53	1.58	1.61	1.60	1.60
	3	1.62	1.29	1.33	1.36	1.35	1.35
	4	1.38	0.88	0.91	0.77	0.72	0.18
2916	163.0	115.0	1.895	0.555	0.151	0.911	
	1	1.87	1.66	1.72	1.74	1.73	1.73
	2	1.75	1.49	1.55	1.57	1.56	1.56
	3	1.58	1.25	1.29	1.32	1.32	1.31
	4	1.33	0.85	0.87	0.74	0.69	0.17

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2917	139.0	114.0	1.807	0.529	0.129	0.903	
	1	1.78	1.58	1.62	1.64	1.63	1.63
	2	1.65	1.39	1.42	1.45	1.45	1.45
	3	1.47	1.15	1.19	1.21	1.21	1.20
	4	1.22	0.74	0.76	0.64	0.61	0.16
2918	148.0	115.0	1.895	0.555	0.138	0.911	
	1	1.87	1.66	1.71	1.73	1.71	1.72
	2	1.74	1.47	1.51	1.54	1.53	1.54
	3	1.56	1.22	1.26	1.29	1.29	1.28
	4	1.31	0.80	0.82	0.69	0.66	0.16
2919	538.0	113.0	5.783	1.692	0.500	0.895	
	1	5.79	3.79	4.28	4.66	4.65	4.73
	2	4.83	2.62	3.34	3.64	3.65	3.66
	3	3.76	1.64	2.14	2.55	2.60	2.58
	4	2.66	0.61	0.61	0.62	0.73	0.47
2920	595.0	114.0	6.950	2.034	0.553	0.903	
	1	6.98	4.54	5.13	5.60	5.59	5.68
	2	5.81	3.12	3.99	4.35	4.36	4.38
	3	4.49	1.89	2.57	3.02	3.07	3.04
	4	3.17	0.63	0.64	0.64	0.79	0.48
2921	496.0	115.0	5.303	1.552	0.461	0.911	
	1	5.32	3.53	3.97	4.31	4.30	4.37
	2	4.46	2.49	3.13	3.40	3.40	3.42
	3	3.51	1.62	1.84	2.38	2.45	2.42
	4	2.53	0.69	0.70	0.78	0.80	0.46
2922	159.0	114.0	1.847	0.541	0.148	0.903	
	1	1.82	1.62	1.67	1.69	1.68	1.69
	2	1.70	1.45	1.51	1.53	1.51	1.52
	3	1.54	1.22	1.26	1.29	1.29	1.28
	4	1.30	0.83	0.86	0.73	0.68	0.17

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA INLET		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2944	37.3	277.4	1.374	0.402	0.035	2.196	
	1	1.35	1.09	1.17	1.20	1.20	1.21
	2	1.22	0.89	0.99	1.04	1.03	1.04
	3	1.05	0.65	0.78	0.82	0.83	0.82
	4	0.84	0.16	0.33	0.29	0.31	0.11
2945	69.3	275.4	2.509	0.734	0.064	2.181	
	1	2.50	2.01	2.14	2.22	2.21	2.22
	2	2.25	1.66	1.84	1.91	1.91	1.92
	3	1.94	1.22	1.44	1.53	1.53	1.53
	4	1.56	0.29	0.59	0.53	0.56	0.12
2946	124.6	273.7	4.446	1.302	0.116	2.167	
	1	4.47	3.58	3.80	3.95	3.95	3.98
	2	4.03	2.97	3.28	3.41	3.42	3.42
	3	3.47	2.17	2.55	2.71	2.74	2.73
	4	2.78	0.50	1.03	0.94	0.99	0.17
2947	508.0	90.4	4.041	1.183	0.472	0.716	
	1	4.04	2.54	2.92	3.19	3.18	3.23
	2	3.31	1.74	2.20	2.43	2.44	2.45
	3	2.52	0.96	1.40	1.64	1.68	1.66
	4	1.73	0.25	0.26	0.34	0.29	0.32
2948	401.0	90.1	2.663	0.779	0.373	0.713	
	1	2.64	1.69	1.94	2.10	2.09	2.13
	2	2.17	1.17	1.46	1.61	1.62	1.62
	3	1.67	0.68	0.95	1.11	1.13	1.12
	4	1.16	0.22	0.23	0.23	0.24	0.24
2949	273.0	90.2	1.401	0.410	0.254	0.714	
	1	1.37	0.91	1.04	1.11	1.11	1.12
	2	1.14	0.66	0.80	0.88	0.87	0.87
	3	0.90	0.43	0.56	0.64	0.64	0.64
	4	0.66	0.21	0.22	0.22	0.23	0.22

TABLE II. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
BORDA INLET		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA

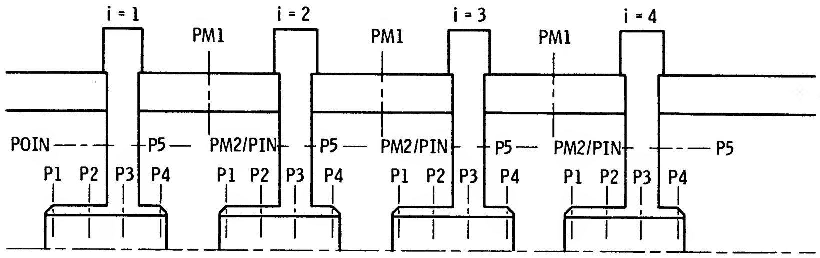
RUN / BORDA	MASS FLOW G/S / INLET	TIN K / POIN MPA	PIN MPA / P1 MPA	PR / P2 MPA	GR / P3 MPA	TR / P4 MPA	POOUT MPA
2950	385.0	126.0	5.361	1.569	0.358	0.998	
	1	5.40	4.13	4.42	4.68	4.66	4.71
	2	4.78	3.42	3.82	4.02	4.03	4.03
	3	4.10	2.73	3.04	3.32	3.35	3.34
	4	3.40	1.91	2.14	1.82	1.75	0.37
2951	310.0	125.4	4.292	1.256	0.288	0.993	
	1	4.31	3.46	3.66	3.82	3.81	3.84
	2	3.89	2.99	3.24	3.38	3.39	3.39
	3	3.44	2.53	2.67	2.89	2.92	2.92
	4	2.95	1.54	1.64	1.48	1.45	0.30
2952	307.0	125.6	4.300	1.258	0.285	0.994	
	1	4.31	3.47	3.67	3.84	3.82	3.85
	2	3.91	3.00	3.26	3.40	3.40	3.40
	3	3.45	2.54	2.69	2.91	2.94	2.93
	4	2.97	1.51	1.63	1.47	1.45	0.30
2953	164.0	165.0	4.903	1.435	0.152	1.306	
	1	4.93	3.95	4.18	4.36	4.35	4.39
	2	4.44	3.26	3.61	3.76	3.77	3.78
	3	3.84	2.39	2.80	2.99	3.02	3.01
	4	3.06	0.54	1.15	1.05	1.13	0.19
2955	91.2	164.0	2.931	0.858	0.085	1.298	
	1	2.95	2.38	2.53	2.62	2.62	2.64
	2	2.66	1.97	2.17	2.26	2.26	2.26
	3	2.30	1.44	1.69	1.80	1.80	1.79
	4	1.83	0.33	0.70	0.63	0.68	0.14
2956	92.1	164.9	2.945	0.862	0.086	1.306	
	1	2.94	2.36	2.51	2.61	2.60	2.62
	2	2.66	1.95	2.16	2.25	2.26	2.26
	3	2.29	1.43	1.69	1.80	1.81	1.80
	4	1.84	0.34	0.70	0.77	0.69	0.14

TABLE II. - Concluded.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2957	66.1	165.9	2.144	0.627	0.061	1.314	
	1	2.13	1.71	1.82	1.89	1.88	1.89
	2	1.91	1.42	1.57	1.63	1.63	1.63
	3	1.66	1.04	1.22	1.30	1.31	1.31
	4	1.33	0.25	0.51	0.46	0.50	0.12
2958	48.9	165.0	1.627	0.476	0.045	1.306	
	1	1.60	1.29	1.39	1.43	1.42	1.43
	2	1.44	1.07	1.18	1.23	1.23	1.23
	3	1.25	0.78	0.93	0.98	0.99	0.98
	4	1.00	0.19	0.39	0.35	0.38	0.12
2959	34.7	163.4	1.167	0.342	0.032	1.294	
	1	1.14	0.92	0.99	1.02	1.01	1.02
	2	1.03	0.76	0.84	0.87	0.87	0.87
	3	0.89	0.56	0.66	0.70	0.70	0.70
	4	0.71	0.14	0.28	0.25	0.27	0.12
2960	34.9	164.6	1.154	0.338	0.032	1.303	
	1	1.13	0.91	0.98	1.00	1.00	1.01
	2	1.02	0.75	0.83	0.86	0.86	0.86
	3	0.88	0.55	0.65	0.69	0.70	0.69
	4	0.71	0.14	0.27	0.25	0.26	0.12

TABLE III. - DATA FOR FOUR SEQUENTIAL, AXIALLY ALIGNED BORDA INLET

TUBES - 0.8-DIAMETER SPACING, INSTRUMENTED SPACERS



RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	PM1 MPA	PM2/PIN MPA
3007	140.7	265.6	4.020	1.176	0.131	2.103			
	1	4.02	1.88	2.50	2.78	2.80	2.86	2.85	2.86
	2		2.57	2.64		2.60	2.59	2.58	2.59
	3		2.20	2.34		2.32	2.28	2.27	2.28
	4		1.87		1.90	1.68	0.21		
3008	79.0	259.8	2.210	0.647	0.073	2.057			
	1	2.19	1.01	1.37	1.50	1.52	1.54	1.54	1.54
	2		1.39	1.43		1.41	1.40	1.40	1.39
	3		1.20	1.27		1.26	1.23	1.25	1.24
	4		1.02		1.06	0.93	0.14		
3009	45.6	259.3	1.291	0.378	0.042	2.053			
	1	1.26	0.59	0.80	0.87	0.88	0.89	0.89	0.89
	2		0.80	0.83		0.81	0.81	0.81	0.81
	3		0.69	0.74		0.73	0.71	0.73	0.72
	4		0.59		0.60	0.55	0.11		
3010	844.1	86.1	4.669	1.366	0.784	0.682			
	1	4.60	0.51	1.53	2.35	2.34	2.44	2.43	2.46
	2		1.95	2.13		2.09	2.09	2.08	2.08
	3		1.75	1.89		1.89	1.84	1.85	1.84
	4		1.64		1.67	1.60	1.62		
3011	865.4	86.8	4.607	1.348	0.804	0.687			
	1	4.53	0.28	0.28	0.70	2.03	2.13	2.12	2.14
	2		1.73	1.89		1.87	1.86	1.86	1.86
	3		1.51	1.66		1.66	1.62	1.62	1.62
	4		1.42		1.43	1.37	1.04		
3013	818.5	85.0	4.092	1.198	0.761	0.673			
	1	4.03	0.24	0.24	0.46	1.77	1.86	1.85	1.88
	2		1.51	1.66		1.64	1.64	1.64	1.64
	3		1.31	1.46		1.45	1.42	1.42	1.41
	4		1.26		1.24	1.19	1.20		

TABLE III. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	PM1 MPA	PM2/PIN MPA
3014	822.1	86.7	4.077	1.193	0.764	0.686			
	1	4.01	0.18	0.18	0.17	0.19	0.21	0.22	0.20
	2		0.20	0.22		0.22	0.23	0.24	0.23
	3		0.26	0.24		0.24	0.24	0.26	0.24
	4		0.24		0.25	0.77	1.09		
3015	490.8	87.9	1.738	0.509	0.456	0.696			
	1	2.16	0.36	0.64	1.13	1.13	1.18	1.18	1.19
	2		0.95	1.06		1.03	1.02	1.03	1.02
	3		0.82	0.93		0.74	0.72	0.73	0.72
	4		0.63		0.65	0.64	0.64		
3016	588.1	117.1	3.840	1.124	0.547	0.927			
	1	3.81	1.22	1.26	1.67	2.20	2.27	2.27	2.29
	2		2.09	2.20		2.19	2.19	2.18	2.19
	3		1.94	2.06		2.06	2.04	2.04	2.04
	4		1.89		1.83	1.62	0.52		
3017	502.6	116.9	3.113	0.911	0.467	0.926			
	1	3.82	1.29	1.33	1.78	2.26	2.33	2.19	2.21
	2		2.13	2.19		2.08	2.04	2.00	2.01
	3		1.85	1.92		1.69	1.67	1.66	1.66
	4		1.54		1.51	1.33	0.99		
3018	726.6	85.8	3.213	0.940	0.677	0.679			
	1	3.15	0.17	0.17	0.16	0.17	0.19	0.19	0.18
	2		0.18	0.20		0.20	0.21	0.22	0.21
	3		0.24	0.22		0.22	0.22	0.24	0.22
	4		0.22		0.24	0.23	0.20		
3019	726.0	86.1	3.206	0.938	0.675	0.682			
	1	3.15	0.17	0.17	0.16	0.18	0.19	0.20	0.19
	2		0.18	0.20		0.20	0.21	0.22	0.21
	3		0.24	0.22		0.23	0.23	0.24	0.23
	4		0.23		0.24	0.24	0.30		

TABLE III. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	PM1 MPA	PM2/PIN MPA
3020	723.3	86.5	3.200	0.936	0.672	0.685			
	1	3.14	0.18	0.17	0.17	0.18	0.20	0.20	0.19
	2		0.19	0.21		0.21	0.22	0.23	0.22
	3		0.25	0.23		0.24	0.24	0.25	0.24
	4		0.23		0.24	0.25	0.39		
3021	719.8	87.0	3.200	0.936	0.669	0.639			
	1	3.14	0.18	0.18	0.17	0.19	0.20	0.21	0.20
	2		0.20	0.22		0.22	0.23	0.23	0.23
	3		0.26	0.24		0.25	0.25	0.26	0.25
	4		0.24		0.26	0.25	0.48		
3022	719.2	87.3	3.206	0.938	0.668	0.691			
	1	3.15	0.19	0.18	0.18	0.20	0.21	0.22	0.21
	2		0.21	0.23		0.23	0.24	0.24	0.24
	3		0.27	0.25		0.25	0.26	0.27	0.26
	4		0.25		0.26	0.31	0.70		
3023	719.9	87.5	3.204	0.938	0.669	0.693			
	1	3.14	0.19	0.19	0.18	0.20	0.21	0.22	0.21
	2		0.21	0.23		0.23	0.24	0.25	0.24
	3		0.27	0.25		0.26	0.26	0.27	0.26
	4		0.26		0.27	0.37	0.80		
3024	718.1	88.0	3.206	0.938	0.667	0.697			
	1	3.15	0.20	0.20	0.19	0.21	0.23	0.23	0.22
	2		0.22	0.24		0.24	0.25	0.26	0.25
	3		0.28	0.27		0.27	0.27	0.28	0.27
	4		0.27		0.65	1.02	1.04		
3025	674.0	88.9	3.311	0.969	0.626	0.704			
	1	3.26	0.58	1.35	1.79	1.78	1.84	1.84	1.85
	2		1.51	1.64		1.61	1.60	1.59	1.60
	3		1.22	1.44		1.44	1.41	1.41	1.40
	4		1.24		1.29	1.24	1.25		

TABLE III. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	PM1 MPA	PM2/PIN MPA
3026	569.1	91.3	3.539	1.036	0.529	0.723			
	1	3.51	1.56	2.23	2.44	2.42	2.47	2.46	2.48
	2		2.26	2.31		2.30	2.27	2.27	2.27
	3		2.04	2.18		2.17	2.13	2.13	2.13
	4		2.03		2.09	2.03	2.04		
3027	568.5	91.4	3.540	1.036	0.528	0.724			
	1	3.52	1.56	2.23	2.44	2.42	2.48	2.46	2.49
	2		2.22	2.31		2.31	2.27	2.27	2.27
	3		2.04	2.18		2.17	2.13	2.13	2.13
	4		2.03		2.09	2.04	2.04		
3028	684.1	101.1	3.441	1.007	0.635	0.800			
	1	3.39	0.44	0.44	0.43	0.51	0.58	0.58	0.57
	2		0.53	0.63		0.64	0.69	0.70	0.69
	3		0.73	0.71		0.71	0.75	0.76	0.75
	4		0.75		0.74	0.74	0.43		
3029	681.2	101.5	3.432	1.004	0.633	0.804			
	1	3.38	0.44	0.44	0.44	0.53	0.59	0.59	0.58
	2		0.59	0.64		0.66	0.71	0.72	0.70
	3		0.74	0.73		0.72	0.77	0.78	0.77
	4		0.76		0.76	0.76	0.45		
3030	676.5	101.9	3.423	1.002	0.629	0.807			
	1	3.37	0.45	0.45	0.45	0.54	0.61	0.62	0.61
	2		0.62	0.66		0.68	0.73	0.74	0.73
	3		0.76	0.75		0.75	0.80	0.81	0.80
	4		0.79		0.78	0.78	0.50		
3031	675.0	102.5	3.427	1.003	0.627	0.812			
	1	3.36	0.46	0.46	0.46	0.56	0.63	0.64	0.63
	2		0.64	0.68		0.71	0.76	0.77	0.76
	3		0.80	0.78		0.78	0.83	0.84	0.83
	4		0.82		0.81	0.82	0.60		

TABLE III. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	PM1 MPA	PM2/PIN MPA
3032	673.6	102.8	3.432	1.004	0.626	0.814			
	1	3.38	0.47	0.47	0.47	0.58	0.65	0.66	0.65
	2		0.66	0.70		0.73	0.78	0.79	0.78
	3		0.81	0.80		0.80	0.85	0.86	0.85
	4		0.84		0.83	0.84	0.65		
3033	670.9	103.6	3.447	1.009	0.624	0.820			
	1	3.39	0.49	0.49	0.49	0.61	0.69	0.70	0.69
	2		0.69	0.74		0.77	0.82	0.83	0.82
	3		0.85	0.84		0.84	0.90	0.91	0.90
	4		0.89		0.88	0.88	0.71		
3034	663.7	104.8	3.455	1.011	0.617	0.830			
	1	3.40	0.52	0.52	0.53	0.67	0.76	0.76	0.75
	2		0.76	0.81		0.84	0.91	0.91	0.91
	3		0.93	0.91		0.94	1.00	1.01	1.00
	4		0.98		0.98	0.96	0.82		
3035	492.5	113.9	2.966	0.868	0.458	0.902			
	1	2.93	1.17	1.21	1.55	1.85	1.91	1.90	1.91
	2		1.77	1.84		1.84	1.84	1.83	1.84
	3		1.66	1.75		1.75	1.73	1.73	1.73
	4		1.62		1.57	1.36	0.46		
3036	484.3	114.5	2.969	0.869	0.450	0.907			
	1	2.93	1.22	1.26	1.62	1.89	1.94	1.93	1.94
	2		1.80	1.87		1.86	1.86	1.86	1.86
	3		1.70	1.78		1.78	1.76	1.77	1.76
	4		1.66		1.58	1.39	0.85		
3037	480.4	114.7	2.972	0.870	0.446	0.908			
	1	2.93	1.24	1.30	1.66	1.91	1.96	1.95	1.97
	2		1.82	1.89		1.89	1.89	1.89	1.89
	3		1.72	1.80		1.80	1.78	1.79	1.78
	4		1.69		1.61	1.43	1.20		

TABLE III. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR		
	BORDA INLET AND SPACER	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	PM1 MPA	PM2/PIN MPA
3038	471.2	115.3	2.981	0.872	0.438	0.913			
	1	2.95	1.31	1.36	1.75	1.87	1.97	1.93	2.01
	2		1.94	2.02		1.93	1.93	1.93	1.93
	3		1.78	1.85		1.86	1.84	1.84	1.84
	4		1.75		1.73	1.61	1.57		
3039	435.9	116.9	3.033	0.888	0.405	0.926			
	1	3.00	1.49	1.58	1.98	2.11	2.15	2.15	2.16
	2		2.01	2.07		2.06	2.06	2.07	2.06
	3		1.93	2.00		2.02	2.00	2.01	2.01
	4		1.93		1.90	1.83	1.81		
3040	782.9	94.1	3.991	1.168	0.728	0.745			
	1	3.93	0.29	0.30	0.28	0.32	0.35	0.36	0.35
	2		0.35	0.38		0.39	0.41	0.42	0.41
	3		0.46	0.43		0.43	0.44	0.50	0.44
	4		0.44		0.44	0.44	0.20		
3041	679.1	94.1	3.110	0.910	0.631	0.745			
	1	3.05	0.30	0.30	0.29	0.33	0.36	0.36	0.35
	2		0.35	0.38		0.40	0.42	0.43	0.42
	3		0.45	0.44		0.43	0.45	0.47	0.45
	4		0.45		0.45	0.45	0.21		
3042	531.8	95.1	2.093	0.613	0.494	0.753			
	1	2.04	0.34	0.34	0.33	0.37	0.40	0.40	0.39
	2		0.40	0.43		0.45	0.48	0.49	0.48
	3		0.49	0.49		0.49	0.52	0.53	0.52
	4		0.51		0.50	0.51	0.25		
3043	358.4	95.4	1.208	0.354	0.333	0.755			
	1	1.17	0.39	0.39	0.39	0.44	0.46	0.47	0.47
	2		0.47	0.49		0.54	0.56	0.56	0.56
	3		0.52	0.55		0.58	0.58	0.59	0.58
	4		0.54		0.53	0.49	0.25		

TABLE III. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR			
BORDA INLET AND SPACER		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	PM1 MPA	PM2/PIN MPA
3044	741.1	106.2	4.177	1.222	0.689	0.841			
	1	4.11	0.53	0.53	0.54	0.69	0.80	0.82	0.81
	2		0.81	0.86		0.89	0.96	0.97	0.95
	3		1.00	0.98		0.98	1.05	1.06	1.05
	4		1.04		1.10	1.02	0.39		
3045	576.1	106.2	2.853	0.835	0.535	0.841			
	1	2.80	0.60	0.60	0.64	0.85	0.93	0.94	0.94
	2		0.93	0.97		1.04	1.11	1.11	1.11
	3		1.05	1.07		1.20	1.20	1.21	1.20
	4		1.09		1.09	1.00	0.40		
3046	445.1	106.5	2.123	0.621	0.414	0.843			
	1	2.09	0.76	0.78	0.91	1.18	1.23	1.23	1.24
	2		1.18	1.24		1.24	1.24	1.24	1.24
	3		1.11	1.18		1.19	1.17	1.18	1.17
	4		1.09		1.05	0.92	0.36		
3047	220.1	106.2	1.292	0.378	0.205	0.841			
	1	1.26	0.94	0.98	1.04	1.05	1.06	1.05	1.06
	2		1.00	1.02		1.00	0.99	1.00	0.99
	3		0.94	0.95		0.92	0.91	0.93	0.91
	4		0.87		0.93	0.71	0.23		
3048	615.9	120.2	4.418	1.293	0.572	0.952			
	1	4.38	1.40	1.45	2.01	2.57	2.65	2.65	2.66
	2		2.42	2.53		2.53	2.52	2.52	2.52
	3		2.23	2.38		2.38	2.35	2.35	2.35
	4		2.17		2.18	1.89	0.56		
3049	413.9	119.8	3.190	0.934	0.385	0.949			
	1	3.17	1.80	1.93	2.28	2.35	2.40	2.40	2.41
	2		2.27	2.32		2.31	2.31	2.31	2.31
	3		2.18	2.23		2.20	2.18	2.19	2.18
	4		2.06		1.92	1.68	0.40		

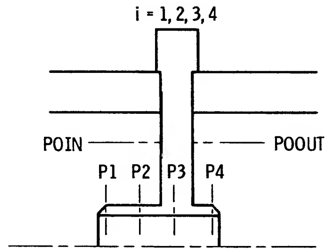
TABLE III. - Concluded.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
3050	246.2	119.4	2.380	0.697	0.229	0.945

BORDA INLET AND SPACER	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	P5 MPA	PM1 MPA	PM2/PIN MPA
1	2.37	1.71	1.84	1.83	1.80	1.82	1.82	1.82
2		1.72	1.71		1.67	1.67	1.67	1.67
3		1.58	1.58		1.53	1.52	1.53	1.52
4		1.43		1.30	1.15	0.25		

TABLE IV. - DATA FOR FOUR SEQUENTIAL, AXIALLY ALIGNED BORDA INLET

TUBES - 0.8-DIAMETER SPACING, UNINSTRUMENTED SPACERS



RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
BORDA INLET		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2962	43.9	253.7	1.248	0.365	0.041	2.009
	1	1.22	0.57	0.78	0.84	0.85	0.86
	2	0.86	0.78	0.80	0.79	0.78	0.78
	3	0.78	0.68	0.71	0.71	0.71	0.69
	4	0.69	0.58	0.61	0.58	0.51	0.11
2963	71.2	255.5	2.016	0.590	0.066	2.023
	1	1.99	0.93	1.26	1.38	1.39	1.42
	2	1.41	1.26	1.31	1.30	1.29	1.28
	3	1.28	1.11	1.17	1.15	1.15	1.13
	4	1.13	0.94	0.98	0.95	0.81	0.13
2964	126.7	256.9	3.560	1.042	0.118	2.034
	1	3.55	1.64	2.22	2.45	2.46	2.51
	2	2.52	2.25	2.33	2.31	2.29	2.29
	3	2.29	1.97	2.08	2.05	2.05	2.02
	4	2.02	1.68	1.72	1.69	1.47	0.19
2965	162.8	259.6	4.587	1.342	0.151	2.055
	1	4.59	2.13	2.84	3.17	3.19	3.25
	2	3.26	2.91	3.02	2.99	2.98	2.95
	3	2.95	2.53	2.68	2.65	2.65	2.61
	4	2.60	2.14	2.21	2.20	1.89	0.24
2966	864.0	85.3	4.433	1.297	0.303	0.675
	1	4.36	0.16	0.22	0.16	0.17	0.19
	2	0.19	0.18	0.19	0.19	0.20	0.20
	3	0.21	0.24	0.22	0.21	0.21	0.22
	4	0.22	0.20	0.23	0.22	0.21	0.15
2967	772.8	85.6	3.620	1.059	0.718	0.678
	1	3.55	0.16	0.18	0.16	0.18	0.19
	2	0.19	0.19	0.20	0.20	0.20	0.21
	3	0.21	0.25	0.22	0.22	0.22	0.22
	4	0.22	0.21	0.24	0.22	0.22	0.08

TABLE IV. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2968	638.7	85.2	2.528	0.740	0.594	0.675	
	1	2.46	0.16	0.18	0.17	0.17	0.18
	2	0.19	0.18	0.19	0.19	0.20	0.20
	3	0.21	0.23	0.22	0.21	0.21	0.22
	4	0.22	0.21	0.23	0.22	0.22	0.12
2969	542.3	85.4	1.893	0.554	0.504	0.676	
	1	1.84	0.17	0.18	0.17	0.18	0.19
	2	0.19	0.19	0.20	0.20	0.20	0.21
	3	0.22	0.23	0.22	0.22	0.22	0.22
	4	0.22	0.22	0.24	0.23	0.23	0.15
2970	477.7	86.3	1.544	0.452	0.444	0.683	
	1	1.49	0.19	0.19	0.19	0.20	0.20
	2	0.20	0.20	0.21	0.22	0.22	0.23
	3	0.23	0.25	0.24	0.24	0.24	0.24
	4	0.25	0.24	0.26	0.26	0.25	0.18
2971	401.5	88.1	1.213	0.355	0.373	0.698	
	1	1.16	0.22	0.22	0.22	0.23	0.23
	2	0.24	0.23	0.25	0.25	0.26	0.28
	3	0.28	0.28	0.28	0.28	0.29	0.30
	4	0.30	0.29	0.31	0.39	0.30	0.20
2972	898.1	85.4	4.791	1.402	0.835	0.676	
	1	4.71	0.16	0.23	0.16	0.17	0.19
	2	0.19	0.19	0.20	0.19	0.20	0.20
	3	0.21	0.25	0.21	0.21	0.21	0.22
	4	0.22	0.20	0.23	0.23	0.22	0.08
2973	779.6	85.6	3.680	1.077	0.725	0.678	
	1	3.61	0.16	0.19	0.16	0.18	0.19
	2	0.19	0.19	0.20	0.20	0.20	0.21
	3	0.21	0.24	0.22	0.22	0.22	0.22
	4	0.22	0.21	0.24	0.23	0.22	0.08

TABLE IV. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2974	529.3	84.8	1.800	0.527	0.492	0.671	
	1	1.75	0.16	0.18	0.16	0.17	0.18
	2	0.18	0.18	0.19	0.19	0.19	0.20
	3	0.21	0.22	0.21	0.21	0.21	0.21
	4	0.21	0.21	0.23	0.28	0.22	0.16
2975	400.8	85.0	1.140	0.334	0.372	0.673	
	1	1.09	0.17	0.18	0.17	0.18	0.18
	2	0.18	0.19	0.19	0.19	0.20	0.21
	3	0.21	0.22	0.22	0.21	0.21	0.22
	4	0.22	0.22	0.23	0.30	0.23	0.18
2976	20.0	86.0	1.416	0.414	0.019	0.681	
	1	1.39	1.39	0.91	1.39	1.39	1.39
	2	1.39	1.39	1.39	1.39	1.39	1.39
	3	1.39	1.39	1.39	1.39	1.39	1.39
	4	1.39	1.39	1.40	1.41	1.41	1.40
2977	381.8	85.7	1.068	0.313	0.355	0.679	
	1	1.02	0.18	0.46	0.19	0.19	0.20
	2	0.19	0.20	0.21	0.21	0.22	0.22
	3	0.23	0.23	0.23	0.23	0.23	0.24
	4	0.24	0.23	0.25	0.30	0.24	0.18
2978	334.4	86.0	0.960	0.281	0.311	0.681	
	1	0.84	0.19	0.24	0.19	0.20	0.20
	2	0.20	0.20	0.21	0.22	0.22	0.23
	3	0.24	0.24	0.24	0.24	0.24	0.25
	4	0.25	0.24	0.26	0.26	0.25	0.19
2979	788.2	114.4	5.184	1.517	0.733	0.906	
	1	5.12	0.68	0.58	0.77	1.13	1.31
	2	1.32	1.31	1.38	1.40	1.42	1.55
	3	1.55	1.58	1.55	1.51	1.62	1.75
	4	1.76	1.62	1.64	1.64	1.55	0.54

TABLE IV. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2980	664.8	114.0	4.087	1.196	0.618	0.903	
	1	4.03	0.86	0.83	1.08	1.66	1.82
	2	1.84	1.88	2.01	2.03	2.02	2.02
	3	2.03	1.69	1.86	1.85	1.86	1.84
	4	1.84	1.58	1.64	1.62	1.46	0.50
2981	506.4	113.3	2.938	0.874	0.471	0.897	
	1	2.95	1.10	1.11	1.44	1.80	1.85
	2	1.86	1.72	1.80	1.80	1.79	1.79
	3	1.80	1.61	1.70	1.69	1.69	1.69
	4	1.69	1.55	1.56	1.51	1.33	0.45
2982	294.9	114.9	2.191	0.641	0.274	0.910	
	1	2.17	1.51	1.38	1.74	1.75	1.77
	2	1.77	1.68	1.69	1.68	1.66	1.66
	3	1.66	1.57	1.58	1.55	1.53	1.52
	4	1.52	1.42	1.40	1.33	1.18	0.30
2983	452.9	113.5	2.396	0.701	0.421	0.899	
	1	3.02	1.09	1.15	1.44	1.82	1.88
	2	1.89	1.75	1.83	1.83	1.82	1.82
	3	1.82	1.63	1.73	1.71	1.35	1.35
	4	1.35	1.24	1.24	1.20	1.06	0.37
2984	250.8	114.3	1.897	0.555	0.233	0.905	
	1	1.88	1.40	1.46	1.54	1.55	1.55
	2	1.56	1.47	1.48	1.46	1.45	1.44
	3	1.44	1.38	1.38	1.35	1.33	1.32
	4	1.32	1.24	1.22	1.14	1.02	0.26
2985	643.7	126.6	5.590	1.636	0.598	1.002	
	1	5.55	1.85	1.26	3.48	3.47	3.57
	2	3.59	3.12	3.33	3.30	3.28	3.29
	3	3.28	2.44	3.04	3.02	3.04	3.02
	4	3.02	2.54	2.70	2.73	2.49	0.60

TABLE IV. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR

BORDA INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA

2986	460.4	126.8	4.347	1.272	0.428	1.004
1	4.33	2.22	2.68	3.20	3.20	3.26
2	3.27	3.02	3.12	3.11	3.09	3.09
3	3.09	2.83	2.95	2.95	2.96	2.95
4	2.95	2.78	2.76	2.71	2.40	0.45
2987	275.5	126.3	3.347	0.980	0.256	1.000
1	3.33	1.91	2.13	2.39	2.42	2.46
2	2.46	2.33	2.34	2.32	2.31	2.31
3	2.31	2.16	2.17	2.14	2.13	2.11
4	2.11	1.94	1.88	1.78	1.60	0.28
2988	146.4	126.2	2.479	0.725	0.136	0.999
1	2.45	1.24	1.60	1.75	1.76	1.80
2	1.80	1.58	1.65	1.64	1.63	1.62
3	1.69	1.40	1.49	1.48	1.43	1.45
4	1.45	1.22	1.27	1.23	1.10	0.15
2989	152.0	163.9	3.223	0.943	0.141	1.298
1	3.18	1.49	1.80	2.20	2.22	2.26
2	2.26	2.03	2.10	2.09	2.06	2.06
3	2.06	1.74	1.86	1.84	1.85	1.83
4	1.83	1.53	1.57	1.53	1.36	0.18
2990	160.3	166.0	3.442	1.007	0.149	1.314
1	3.44	1.63	1.95	2.40	2.41	2.45
2	2.46	2.21	2.28	2.26	2.24	2.23
3	2.24	1.91	2.03	2.01	2.00	1.98
4	1.98	1.60	1.66	1.71	1.44	0.19
2991	133.6	166.8	2.876	0.842	0.124	1.321
1	2.87	1.35	1.62	2.00	2.00	2.04
2	2.05	1.84	1.90	1.89	1.86	1.86
3	1.86	1.57	1.68	1.66	1.65	1.63
4	1.62	1.35	1.39	1.36	1.21	0.16

TABLE IV. - Continued.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR
BORDA	INLET	POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA

RUN / BORDA	MASS FLOW G/S / INLET	TIN K / POIN MPA	PIN MPA / P1 MPA	PR / P2 MPA	GR / P3 MPA	TR / P4 MPA	POOUT MPA
2992	113.8	164.9	2.473	0.724	0.106	1.306	
	1	2.44	1.15	1.59	1.70	1.71	1.74
	2	1.74	1.56	1.61	1.60	1.58	1.58
	3	1.58	1.33	1.42	1.41	1.42	1.40
	4	1.40	1.17	1.20	1.18	1.04	0.15
2993	63.8	164.3	1.428	0.418	0.059	1.301	
	1	1.38	0.65	1.18	0.97	0.97	0.99
	2	0.99	0.89	0.91	0.91	0.90	0.89
	3	0.90	0.76	0.82	0.80	0.81	0.80
	4	0.80	0.67	0.70	0.67	0.61	0.12
2994	36.6	165.2	0.849	0.248	0.034	1.308	
	1	0.82	0.39	0.84	0.58	0.57	0.59
	2	0.59	0.53	0.54	0.54	0.53	0.53
	3	0.53	0.45	0.48	0.48	0.47	0.47
	4	0.47	0.39	0.41	0.40	0.36	0.11
2995	44.8	165.3	1.000	0.293	0.042	1.309	
	1	0.96	0.45	0.67	0.67	0.67	0.69
	2	0.68	0.62	0.63	0.63	0.62	0.62
	3	0.62	0.54	0.57	0.56	0.56	0.55
	4	0.55	0.46	0.49	0.48	0.42	0.11
2996	846.1	101.3	4.947	1.448	0.786	0.802	
	1	4.88	0.40	0.35	0.41	0.48	0.55
	2	0.55	0.56	0.60	0.62	0.62	0.65
	3	0.66	0.73	0.70	0.67	0.68	0.71
	4	0.71	0.71	0.74	0.75	0.71	0.30
2997	733.5	101.6	3.918	1.147	0.682	0.804	
	1	3.85	0.43	0.43	0.44	0.52	0.59
	2	0.58	0.60	0.64	0.66	0.66	0.70
	3	0.70	0.76	0.73	0.71	0.72	0.76
	4	0.76	0.76	0.77	0.75	0.77	0.31

TABLE IV. - Concluded.

RUN	MASS FLOW G/S	TIN K	PIN MPA	PR	GR	TR	
BORDA INLET		POIN MPA	P1 MPA	P2 MPA	P3 MPA	P4 MPA	POOUT MPA
2998	620.3	101.7	2.968	0.869	0.576	0.805	
	1	2.91	0.46	0.47	0.47	0.57	0.63
	2	0.63	0.64	0.68	0.69	0.70	0.75
	3	0.76	0.78	0.77	0.75	0.77	0.82
	4	0.82	0.80	0.81	0.80	0.80	0.82
2999	494.6	101.1	2.090	0.612	0.460	0.800	
	1	2.04	0.49	0.49	0.52	0.63	0.68
	2	0.68	0.68	0.71	0.72	0.76	0.80
	3	0.81	0.77	0.78	0.78	0.85	0.86
	4	0.86	0.78	0.82	0.81	0.74	0.82
3000	383.4	101.0	1.534	0.449	0.356	0.800	
	1	1.49	0.56	0.56	0.62	0.78	0.82
	2	0.82	0.81	0.86	0.89	0.89	0.89
	3	0.89	0.80	0.84	0.84	0.84	0.84
	4	0.84	0.76	0.79	0.76	0.67	0.30
3001	251.9	101.1	1.118	0.327	0.234	0.800	
	1	1.09	0.67	0.70	0.79	0.83	0.84
	2	0.84	0.80	0.82	0.82	0.81	0.82
	3	0.82	0.77	0.79	0.78	0.77	0.77
	4	0.77	0.72	0.72	0.68	0.60	0.24
3002	19.0	107.0	2.114	0.619	0.018	0.847	
	1	2.11	2.11	1.96	2.10	2.10	2.10
	2	2.11	2.10	2.11	2.11	2.10	2.10
	3	2.11	2.10	2.10	2.10	2.10	2.10
	4	2.10	2.10	2.10	2.27	2.11	2.10
3003	9.0	117.0	2.138	0.626	0.008	0.926	
	1	2.14	2.13	2.13	2.14	2.13	2.13
	2	2.13	2.13	2.13	2.13	2.13	2.13
	3	2.13	2.13	2.13	2.13	2.12	2.12
	4	2.12	2.12	2.13	2.15	2.13	2.13

TABLE V. - CALCULATED AND EXPERIMENTAL VALUES FOR FOUR SEQUENTIAL BORDA INLETS AT SPACINGS OF 30 DIAMETERS

Run	Reduced inlet stagnation pressure, $P_{R,0}$	Reduced inlet stagnation temperature, $T_{R,0}$	Reduced mass flow rate		Pressure ratio							
					For inlet 1		For inlet 2		For inlet 3		For inlet 4	
			Experimental, $G_{R,exp}$	Calculated, $G_{R,calc}$	Experimental, $X_{1,exp}$	Calculated, $X_{1,calc}$	Experimental, $X_{2,exp}$	Calculated, $X_{2,calc}$	Experimental, $X_{3,exp}$	Calculated, $X_{3,calc}$	Experimental, $X_{4,exp}$	Calculated, $X_{4,calc}$
3070	0.366	1.701	0.030	0.027	0.90	0.89	0.85	0.86	0.81	0.79	------	0.52
3071	.609	1.754	.049	.045			.86		.79		------	
3072	1.089	1.859	.087	.079			.85		.79		------	
2863	.307	2.22	.022	.020			.86		.80		------	
2866	1.779	2.27	.125	.116	.89		.86		.79		------	
2868	.404	2.25	.029	.026	.88		.87		.79		------	
3051	1.448	.68	.544	[a].529, .506	.82	[a].77, .79	.75	[a].70, .74	.67	[a].58, .64	------	[a].265, .44[a]
3053	.931		.422	.420	.82	.77	.76	.70	.68	.56	------	.43
3055	.585		.33	.303	.82	.81	.76	.76	.71	.68	------	.55
3056	.454		.28	.25, .21	.83	.83, .88	.78	.79, .86	.71	.74, .81	------	.675, .8

[a]Dual entries indicate forced convergence.

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16. Abstract

Choked flow rate and pressure profile data were taken and studied for a configuration consisting of four axially aligned, sequential Borda tubes of 1.9 length-diameter ratio with separation distances of 0.8 and 30 tube diameters. For either case the flow rate data could be represented by a flow-coefficient-reduced temperature plot. At a separation distance of 30 tube diameters the pressure profiles dropped sharply at the entrance and recovered within each Borda tube; except at low temperatures, where fluid jetting through the last Borda tube occurred. At a separation distance of 0.8 tube diameter fluid jetting was prevalent, and application of a significant backpressure did not alter the jetting. These results agree with other data for tubes with Borda or sharp-edge-orifice inlets and with a water flow visualization study reported herein.

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